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Drawing-to-Learn: Active and Culturally Relevant Pedagogy for Biology

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Students enter biology classrooms with ideas about the natural world already formed. Teachers can help students construct new knowledge by using active, culturally relevant pedagogy and by making space in their lesson for students to reveal, challenge, and/or reconcile their preconceptions with new knowledge. Drawing meets all of these needs. Drawing-to-learn (DTL) allows students to be metacognitive and creative as they generate concrete representations of their abstract conceptions. In this case study of biology classes for Tibetan Buddhist monastic students through the Emory-Tibet Science Initiative, we find that DTL engages students in active learning, allows multi-modal visualization and discourse about mental models, and beyond this, solicits cultural references from both students and teachers.

Keywords: drawing-to-learn, monastics, Tibet, biology, teacher-student discourse

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INTRODUCTION

For years, researchers have implored biology instructors to use active learning pedagogy to help increase student understanding of biology concepts and to strengthen class performance (Freeman et al., 2014; Haak et al., 2011; Theobold et al., 2020). Strategies such as writing-to-learn (WTL), small group work, and problem solving in project-based assignments encourage students to explore content more deeply, to recall prior knowledge, and to articulate their developing conceptions (Andrews et al., 2011). The efficacy of active learning has been well demonstrated (Deslaurier et al., 2019; Freeman et al., 2014; NRC, 2003), except when instructors are unaware of how to design meaningful activities (Andrews et al., 2011; Bloodhart et al., 2020).

One of the intentions of active learning pedagogy in biology classes is for both students and teachers to uncover student's preconceptions about the natural world. These preconceptions may reflect student's cultural or personal funds of knowledge, the socioculturally-informed knowledge that has been acquired in one's daily life (Moje et al., 2004; Moll, 2019). Not all active learning strategies are equally successful in 1) prompting discourse that allows students to reconcile potentially conflicting conceptions about the natural world and 2) revealing students' ways of knowing (Balgopal et al., 2012; Balgopal et al., 2021). If teachers wish to introduce students to new ways of knowing, both must have a chance to identify prior knowledge and any worldviews affecting student explanations of natural phenomena, as these are potential reasons for student's confusion or alternative conceptions. Moreover, teachers need pedagogical practices that make abstract conceptions salient (Balgopal et al., 2017; DeNoyelles and Reyes-Foster, 2015).

Science instructors have long depended upon images in their textbooks, lectures, and assessments, yet research on drawing-to-learn in science classes has been sparse, especially when compared to writing-to-learn (Bell, 2014; Prain and Tytler, 2012; Tippett, 2016; Yore et al., 2003). In this paper, we adhere to Quillin and Thomas' (2015) definition of drawing: "a learner-generated external visual representation depicting any type of content, whether structure, relationship, or process, created in static two dimensions in any medium (p. 2)." Note that this definition is broad in regard to content but narrow in its insistence upon student creation-not only interpretation-of visuals. Thus, an instructor's frequent use of diagrams, figures, maps, or charts is not, in and of itself, a use of DTL pedagogy (Tippett, 2016). No matter how often students are asked to interpret symbols and images in their science classes, for strong visual literacy, they need to create their own representations of science concepts and phenomena (Lowe, 2000; Schonborn and Anderson, 2006; Gilbert and Treagust, 2009; Ainsworth, 2011). In other words, students must actively choose content and composition, and must, themselves, generate a material illustration. In doing so, students have the freedom to draw upon cultural references and symbols.

DTL can take many forms in the classroom. Drawing can fill large portions of laboratory notebooks, where students keep records of specimens, experiments, and observations (Germann and Aram, 1996). Shared drawings can serve as essential prompts and tools for class or small group discussions (Atkins Elliot et al., 2016; Goldschmidt, 2007; Lowe, 2000; Park et al., 2020). Drawing can be tied to journaling, an exercise that can also prompt students to use expressive writing to explore a topic (Cormell and Ivey, 2012; O'Keefe and Paige, 2020). In their comprehensive DTL review, Quillin and Thomas (2015) provided a valuable list of 13 reasons drawing may be integrated into science curricula, including drawing to: interpret visual information, enhance motivation, reveal misconceptions, support learning, enhance observation, enhance model-based reasoning, connect concepts and ideas, enhance metacognition, convey quantitative information, teach skills, reinforce the role of visual design in science communication, reveal student's mental models, and communicate to others. We argue that the last two in this list make DTL uniquely well-suited to call attention to, or make salient, student's worldviews and thus to help both students and teachers reconcile new biology concepts with diverse preconceptions. We share here, as a case study, the drawing activities we integrated throughout our biology instruction of Tibetan Buddhist monastics in the Emory-Tibet Science Initiative (ETSI).

METHODS

We have used a case study methodology (Yin, 2009) to explore the role that DTL interventions can have in promoting communication between instructor and students in biology courses for adult monastics. Such case study research is especially useful for phenomena in temporally- and spatially bounded contexts (Stake, 2005) and provides a naturalistic approach to learning about the process and product of the case(s) being studied (Stake, 1995). Using an intrinsic case study design, we sought to characterize the unique role that DTL played in cross-cultural biology classes for Tibetan Buddhist monks living in India (Crowe et al., 2011).

Context

Emory University in the United States (U.S.) and monastic universities in Tibetan settlements in India collaboratively created the ETSI program to offer academic natural science instruction to Buddhist monastics (monks and nuns). Science instructors from a wide range of universities were invited over a decade to participate in teaching biology, neuroscience, physics, and philosophy of science courses. Currently, monastic science leaders are transitioning to be lead instructors at their universities. Monastic students ranged in age from early-30's to mid-40's, and around 100 students were enrolled in each course. Because monks and nuns resided at separate institutions, classes were not often co-ed. Both authors have participated in the program (AFE for 7 years and MMB for 5 years), teaching biology courses to monastics or assisting monastic science teachers in curriculum development.

Courses and Interventions

Outside of ETSI, both authors have integrated WTL and DTL into our undergraduate biology courses in the U.S. In our ETSI biology courses, we used a variety of DTL activities, including both in class and homework drawings, conducted collaboratively or alone, as stand-alone assignments or in conjunction with other activities, in notebooks, on index cards, on large pieces of butcher paper, or on other media, and in English, Tibetan, or whatever symbols were meaningful to the student. We most often and regularly asked students to keep class journals, notebooks in which they recorded and reflected on concepts. These were then voluntarily shared in class with peers and the instructors. Our WTL/DTL assignments were both observational (recording what they saw during class activities) and conceptual (recording abstract ideas on paper), but for this case study we focused on the conceptual assignments. Conceptual assignments required students to recall their prior knowledge (academic, personal, theological/cultural, linguistic, etc.), as they negotiated new biological knowledge introduced in their ETSI courses.

Data Collection and Analysis

The primary source of data used in this study included recorded images (photographs) of student-created drawings. Other data referenced in the analysis included: audio-recordings and transcripts of translations of student explanations of their drawings, curricular materials, reflections of our teaching experiences during the respective courses, and recorded images of artwork and drawings that we observed at the monastic universities and Tibetan settlement during our teaching experiences. After obtaining Institutional Review Board approval (053-16H) from Colorado State University, we methodically recorded images of the WTL/DTL assignments and student work. Students were invited to have their notebooks, journals, and drawings photographed. ~25% of each ~100 student class volunteered. If they or a translator explained what the images were (i.e., cultural significance), these explanations were audio-recorded or documented in English. All images and recordings were stored in a shared cloud-based folder. Using thematic analysis, we iteratively reviewed all of our respective images independently (Braun

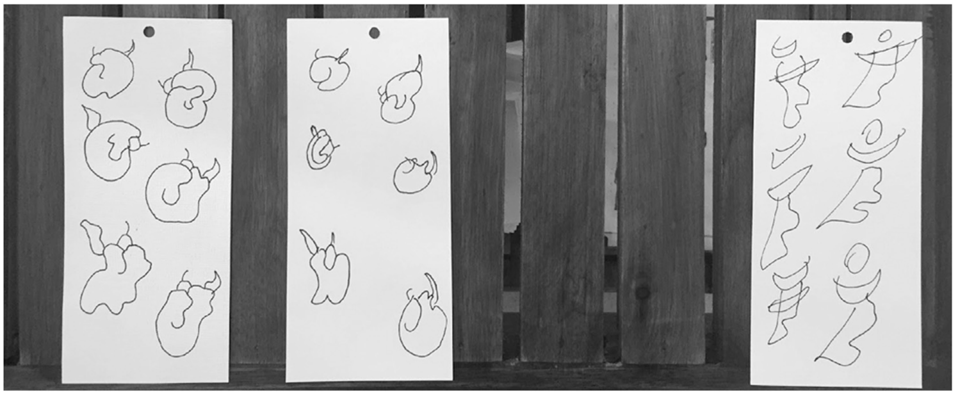

FIGURE 1 | A drawing activity used to illustrate the concept of accumulated mutations. Students saw images on a card **(far left)** and recreated them. Over 100 students participated, but after only 30 students had recreated the images **(far right)**, the images were already drastically different.

and Clarke, 2006) through a deductive analytic process using Quillin and Thomas (2015)'s typology and identified initial themes: enhancing meta-cognition, revealing misconceptions, and visualizing quantitative data (**Supplementary Appendix**). We initially grouped drawings based on the type of drawing: observational, conceptual, realistic, or abstract. We defined observational drawings as recordings of what monastics saw, while conceptual drawings were of ideas generated in or out of class. Realistic drawings were recognizable to both the viewer and the drawer, while abstract illustrations were meaningful to primarily the drawer, unless the viewer was familiar with symbols, colors, and orientations of the drawings. We also identified an additional code (fostering cross-cultural discourse) that was not emphasized in Quillin and Thomas (2015) and selected examples to exemplify our findings. After returning to the DTL and visual literacy literature, we finalized our themes and ensured full inter-rater agreement.

RESULTS

We found that when teachers and students bring different cultural perspectives to class, the concrete drawings generated through DTL activities, such as those we used in our ETSI classes, can enrich class discussions in two prominent ways. First, as with most active learning strategies, DTL is multi-modal, engaging students in not only the creation of visual drawings but in associated verbal discussion and written text. Second, DTL focuses both student and teacher attention on reconciling academic knowledge with cultural funds of knowledge.

Drawing to Promote Active Learning

As biology instructors in the ETSI program, we described processes –– both biological processes (e.g., cell division, speciation), and research processes (how investigations are designed and conducted). Teaching processes can be challenging because of temporal or spatial constraints and/or because they involve multiple steps. During a lesson that one of our co-instructors (Nicole Gerardo) taught about how the accumulation of microevolutionary changes (e.g., mutations) results in large macroevolutionary outcomes (e.g., speciation), ETSI monastic students participated in a drawing exercise asking each of them to recreate a squiggle drawing. Each student saw only the squiggle drawing created by the last person (**Figure 1**). After passing through 100 students in the class, the squiggle drawings accumulated so many small changes that they no longer resembled the original drawings. These drawings on cards were hung up around the room, where they demonstrated a process and reinforced an abstract concept about variation that was new to our adult learners. Although students were actively engaged in this exercise and tried to draw with exactitude, they were not necessarily trying to communicate something; the teachers were. The drawings strengthened our class discussion of the principle of variation.

In a second, active learning DTL exercise, we asked our students to create illustrations of a research design and the data it would yield (**Figure 2**). We set up, as a class, a simple study of the variables involved in radish seed germination and growth. The variables selected by the monastic students included light, temperature, and water. We then encouraged each of them to visualize the research process, draw it, and fill in a record of their investigation and data. The students created a variety of ways to illustrate the study, demonstrating the diversity of visualizations of their mental models. Each time they met with us to discuss their findings, we encouraged them to use their drawings to support the conversations. We found many students created matrices, often with illustrations of the treatments as cups (which we had provided to students to hold the soil and seedlings). Not only were these drawings intended to remind students of their experimental design, but drawings were also explanatory tools that could support student claims during discussions with peers and with instructors.

Drawing-to-Learn and Cultural Relevance

In the example of squiggle mutation, the drawing activity provided a visual to represent the instructor's conception. In the example of research design, students had the opportunity to share their own conceptions. Beyond 1) actively engaging each

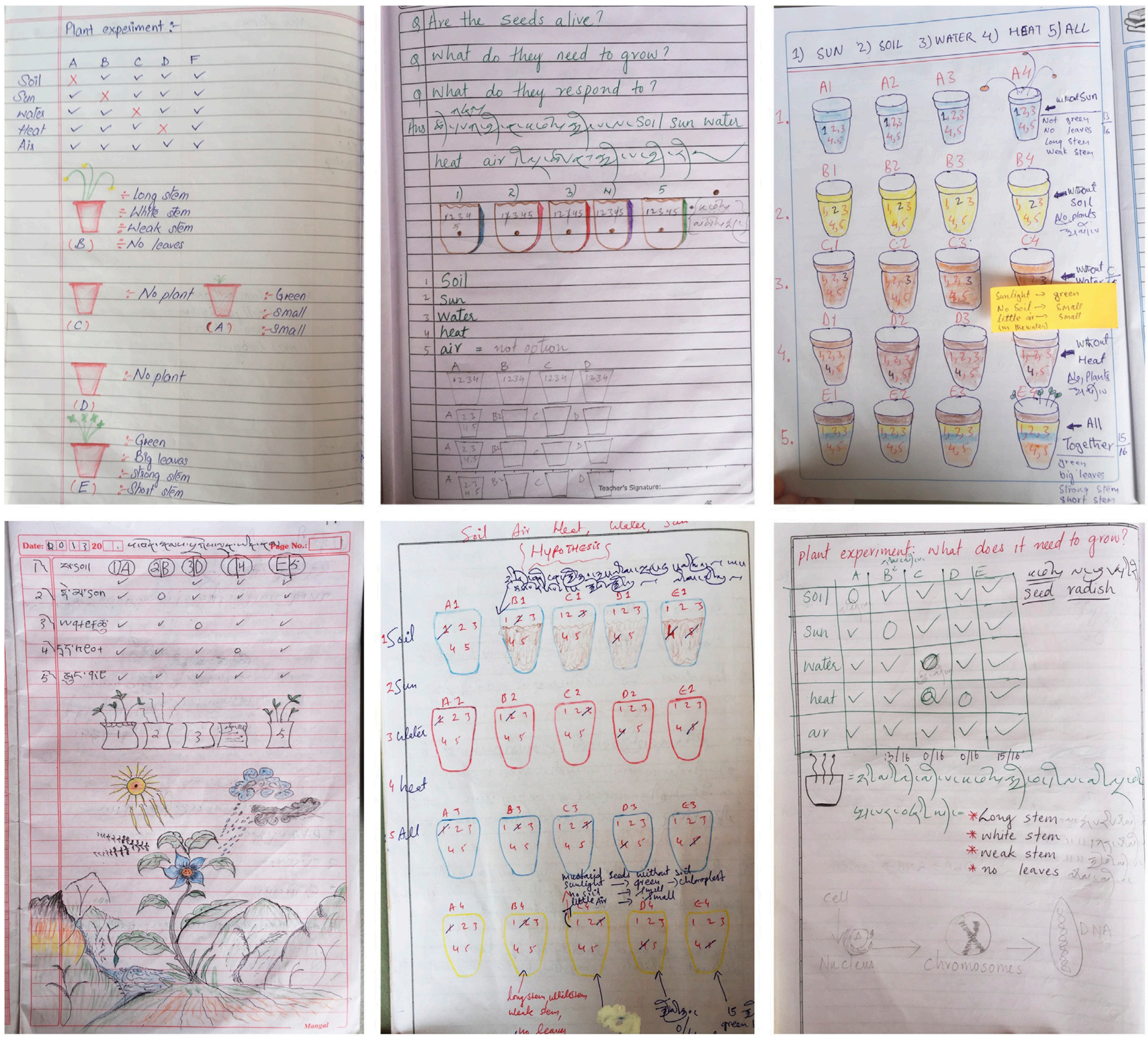

FIGURE 2 | A data visualization activity from six student's notebooks, representing a class study of variables affecting radish seed germination and growth. Student matrices were personally meaningful and distinct.

student and 2) concretizing their mental conceptions; however, DTL also 3) fosters multi-modal and culturally relevant communication. As students notice elements in their own drawings that reinforce or challenge their preconceptions of the natural world, the visuals can become focal points for written and verbal exploration in journals and with peers and instructors in the classroom. We have selected three examples of DTL fostering such discourse and moving students towards reconciliation between cultural/theological and academic/biological explanations.

Sperm and Sinboos

After a developmental biology lesson about sperm forming in the testes, multiple monks drew similar diagrams in their journals of a man's outline filled with sperm (**Figure 3A**). Examples were projected by a document camera on the board, so students could explain their ideas. We learned that many of the monks had been warned that during ejaculation, energy and power would drain from their bodies and minds (as evidenced by the whole-body lassitude felt beyond just the testes). Together, we reconciled different cultural and academic explanations by concluding that although swimming sperm were only generated in the testes, the nutrients for their formation, and that of the fluid semen, come from throughout the body. These drawings (**Figure 3A**) also sparked further discussion about small life forms, "sinboo" (སྲིན་བུ), including our human cells and bacteria that form microbiomes, that live in and on a person's body. The students described a common mealtime blessing recited in gratitude for

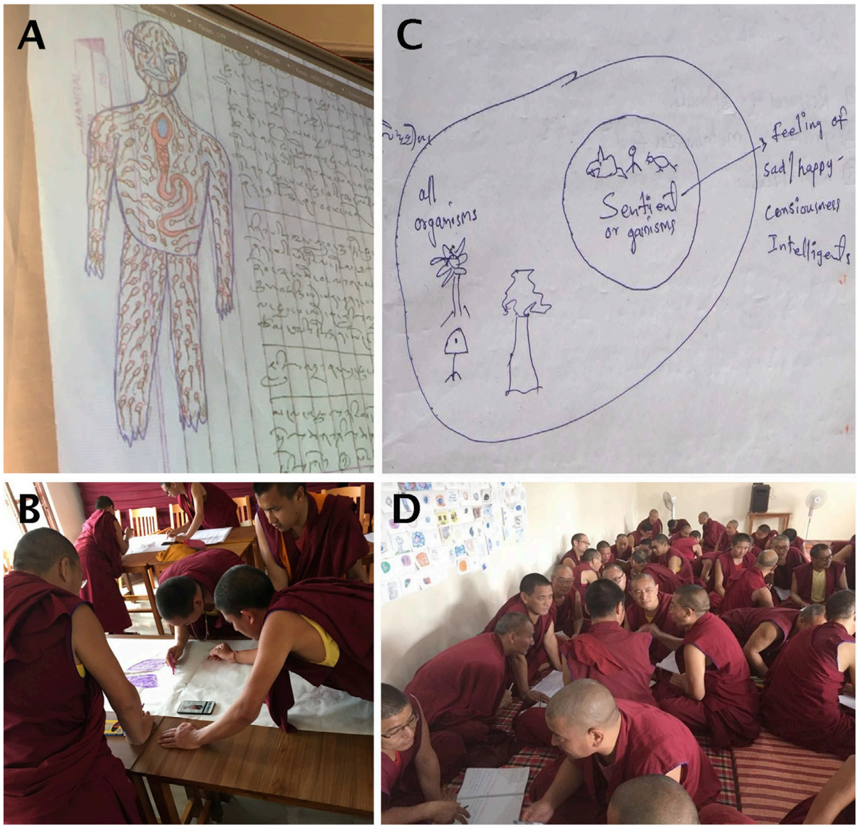

FIGURE 3 | DTL and culturally relevant ways of knowing in the biology classroom. **(A)** Journal drawing of sperm all over the male body. **(B)** Monks drawing life-size diagrams of the human body on butcher paper, using red/blue/yellow crayons to label the products of mesoderm/ectoderm/endoderm (the three embryonic germ-layers). **(C)** Journal drawing of a Venn diagram showing the monastic's distinction between living things and living beings. **(D)** Monastics using journal drawings as evidence during small group discussions.

the meal's nourishment helping not only the human body, but also many sinboo within, and dependent upon, that body. The monks expressed pride that Buddhists had known about such tiny lives before microscopes were invented and felt this to be an instance of satisfying overlap between biology and theology. The sinboo drawings were not intended to be observational but were conceptual and culturally meaningful to the students. While the instructors initially interpreted the drawings as misunderstandings, further discussion revealed that, in fact, there were deep commonalities and only superficial conflicts between the student's and instructor's ideas.

Two or Three Tissue Contributions

During a lesson on three embryonic germ layers (ectoderm, mesoderm, and endoderm), and which tissues originated from each, we (with co-instructor Christopher Brandon) asked monks to trace the outline of a classmate on butcher paper and fill it in using blue, red or yellow crayons to show the organs and structures produced by each germ layer (**Figure 3B**). We hung these colorful, life-size drawings around the classroom walls. Students commented repeatedly that the lesson on three germ layers differed from their previous conception of the body forming from two sources, male and female. For example, traditionally, they believed that bones and blood were contributed by different parents. As we became aware of this (two *vs.* three tissue origin) discrepancy, we asked the students to consider how their butcher paper drawings would differ, if based on the traditional rather than new teachings. The germ layer drawings led to an exploration of male and female contributions from multiple perspectives and brought cultural context into our science lesson (Fox Keller and Scharff-Goldhaber,1987). We found ourselves speaking with the students about the efforts of developmental biologists to form bi-maternal or bi-paternal embryos, and about the risk of presuming sperm cells to be active or masculine and egg cells to be passive or feminine (Martin, 1991). In this way, drawings extended our lesson to include how even scientists may be seeing cultural beliefs as though "they were part of nature" (Martin, 1991).

Living Things *vs.* Living Beings

During class discussions about the characteristics of life (e.g., organization as cells, genetic inheritance, ability to respond to stimuli), we (with co-instructor Nicole Gerardo) invited students to write and draw in their journals and then to discuss in small groups, while using their journal entries to support their arguments. One student used a Venn diagram in his journal to represent a distinction he found between all living organisms and those that are sentient (**Figure 3C**). When the journal drawing was recreated on the board, many other students agreed that all living things share characteristics, but animals remain distinct from bacteria, plants, and fungi, because animals are capable of self-awareness and suffering. The monks referred to animals as "living beings," while they called other organisms "living things." The drawing prompted a further discussion about whether or not awareness of one's own emotions is a defining characteristic of life (**Figure 3D**), and how to illustrate when this trait evolved. More importantly, this drawing allowed students and instructors to learn from one another and about the interplay between different types of knowledge.

DISCUSSION

The case study we share here on drawing-to-learn pedagogy in ETSI biology courses reveals benefits to the use of DTL in culturally diverse classrooms. Like writing-to-learn, DTL engages students in active learning and can support multi-modal (visual, written, and spoken) exploration of mental models. Beyond this, DTL also solicits cultural references from both students and teachers, allowing everyone to explore areas of reinforcement or dissonance between academic and cultural funds of knowledge (Balgopal et al., 2021; Moje et al., 2004). Given that one of the aims of the ETSI program is to foster cross-cultural understanding, especially as they navigated both theological and scientific teachings, we found that DTL was a particularly relevant pedagogical approach. DTL was also well-suited to the ETSI context because students were learning new and translated terminology, and because it complemented rhetorical strategies with which students were familiar. Dialectical debate is central to monastic education, and our students discovered that drawings could be used as supportive evidence during such discourse. In the process of meaning making during debates and discussions, monastic students could make links between academic and cultural concepts, or, other times, found resolution between disparate ideas by border crossing - moving between two ways of knowing (Balgopal et al., 2021).

Inspired by our experience with DTL as instructors in Buddhist monastic universities, we posit that DTL can be relevant across educational contexts. Visualizations of mental models reveal for both learner and teacher what is clear and messy, as students make sense of new concepts (Dikmenli, 2010). Both disorderly writing and drawing can reveal disorderly thinking. Teachers in all contexts need to assess learning, while guiding students. Drawings provide that needed window into student's minds. Every line in a drawing *tells*; every line makes an assertion and reveals a person's choices in assembling, interpreting, and using facts. The American adage "a picture is worth a thousand words" reminds us that drawings are distillates of sometimes wordy, inefficient, or obfuscating written text. Non-verbal representations can also foster communication, by initiating and anchoring verbal articulations. When journal entries contain both visuals and written text and are then further used in class discussions, they are naturally multi-modal (Kress et al., 2014; Park et al., 2020). Drawings make unique tools for in-class discussions, where they support problem solving in real-time and a shared space (Atkins Elliott et al., 2016). In short, tacit meanings are exposed, and "the viewer can be drawn into a dialogue with the image" and with peers and instructors (Rowsell et al., 2012, p. 447).

We extend Quillin and Thomas's (2011) list of DTL's benefits to include "uncover cultural knowledge." In this case study, we have demonstrated that DTL can help make cultural knowledge explicit and potentially help learners reconcile different worldviews, while informing instructors of where tensions or confusions (or just alternative conceptions) arise (e.g., Balgopal et al., 2021). Conceptual revelations may be even more important in situations when students and teachers may not be fluent in one another's primary language (Gray et al., 2020). Although our case study was populated with learners and teachers who brought very different types of knowledge to class discussions, DTL has broad benefits across a range of academic contexts. For example, science teachers across levels (primary to collegiate classrooms) are known to use metaphors and analogies to illustrate concepts to learners, but unless students have a chance to explore and visualize these, their interpretations may differ from those of their instructors (Duit et al., 2001; Brown and Salter, 2010). Other benefits of DTL include exploring temporal and spatial processes together, as a class. Often these processes are illustrated with abstract symbols (e.g., flow charts with arrows for the central dogma of biology) or as abstract images (e.g., stylized cartoon drawings of cell organelles). Yet, much of the research on this type of visual literacy continues to focus on how students interpret images, and not on how they convey their own conceptions through their own images (e.g., Schönborn and Anderson, 2006; McTigue and Flowers, 2011). We believe that DTL's utility for fostering bi-directional learning (between students and teachers) warrants further study.

We encourage biology instructors to explore creative ways of integrating DTL into their curricula, even in contexts with shared or similar worldviews. DTL reveals nuanced understandings of the natural world that students may not be able to articulate in written or spoken text and does so in an all-in-one, holistic product (Wilson and Rigakos, 2016). Alternatively, drawings can quite naturally accompany written and verbal assignments, allowing students to make use of multiple modalities. As seen in previous WTL studies, students who are given permission to share through class activities will reference unanticipated personal and cultural funds of knowledge (Balgopal et al., 2017; Chang, 2018). We acknowledge that our case study was limited by only examining the drawings of monks (when monastic students also include nuns), and by focusing on drawn artifacts and in class observations, rather than written artifacts and audio-recordings of monastics explaining their drawings (these are being analyzed for a different study). Nonetheless, our findings on DTL, as an active and culturally relevant teaching strategy remain.

In summary, DTL can provide both teachers and students with windows into each other's minds, can make the unseen seen, and can foster multi-modal discourse and integration of diverse conceptions of the natural world. Given that drawing is "generative and material; it calls forth the presence of the person who created it" (Fink, 2020) to bring special benefit to the biology classroom.

DATA AVAILABILITY STATEMENT

The anonymized data supporting the conclusions of this article will be made available by the authors, upon reasonable request.

ETHICS STATEMENT

This study involving human subjects was reviewed and approved by the Institutional Ethics Review Board of Colorado State University (protocol #053-16H). Written and/or oral informed consent was obtained from the participants for the publication of any potentially identifiable images or data.

AUTHOR CONTRIBUTIONS

Both authors conceived the study, collected and analyzed the data, and wrote the paper.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2021.739813/full#supplementary-material

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