# Instructional improv to analyze inquiry-based science teaching: Zed's dead and the missing flower

Maggie Dahn[1*] ⓘ, Christine Lee[2] ⓘ, Noel Enyedy[3] ⓘ and Joshua Danish[4] ⓘ

* Correspondence: dahnm@uci.edu
[1]University of California, Irvine, Irvine, USA
Full list of author information is available at the end of the article

## Abstract

In inquiry-based science lessons teachers face the challenge of adhering to curricular goals while simultaneously following students' intuitive understandings. Improvisation (improv) provides a useful frame for understanding teaching in these inquiry-based contexts. This paper builds from prior work that uses improv as a metaphor for teaching to present a translated model for analysis of teaching in an inquiry-based, elementary school science lesson context. We call our model *instructional improv,* which shows how a teacher spontaneously synthesizes rules of improv with teaching practices to support student learning, engagement, and agency. We illustrate instructional improv through case study analysis of video recorded classroom interactions with one teacher and 26 first and second grade students learning about the complex system of honey bee pollination in a mixed reality environment. Our model includes the following defining features to describe how teaching happens in this context: the teacher 1) *tells a story*; 2) *reframes mistakes as opportunities*; 3) *agrees*; 4) *yes ands*; 5) *makes statements (or asks questions that elicit statements)*; and 6) *puts the needs of the classroom ensemble over individuals*. Overall, we show how instructional improv helps explain how teachers can support science discourse and collective storytelling as a teacher (a) shifts power and agency to students; (b) balances learning and agency; and (c) makes purposeful instructional decisions. Findings have immediate implications for researchers analyzing interactions in inquiry-based learning environments and potential future implications for teachers to support inquiry learning.

**Keywords:** Improvisation, Discourse, Mixed reality, Science education, Student-driven, Inquiry-based learning, Inquiry-based teaching, Student agency, Elementary education, Storytelling

## Introduction

Improvisation (improv) can be a productive lens through which to analyze teaching during classroom interactions. As teachers plan lessons, activities, and imagined conversations that reflect the architecture of what they wish to teach, they also must adapt to accommodate for the situated action of what happens in the classroom based on what students are ready to learn (Suchman, 1987). Too much rigid structure and

adherence to a teacher's plan limits learning because it does not leave room for existing knowledge to be relevant or for students to be active participants in their own learning. However, too much responsiveness without a plan to guide lessons toward a logical goal may lead to learning *something* but will be less likely to lead to learning the intended curriculum. This challenge that teachers face in simultaneously guiding inquiry and facilitating student autonomy is common in curriculum research related to teacher decision-making (e.g., Penuel et al., 2014).

Using a flexible, improvisational approach can support teachers in finding a balance between their plans and student agency, which is key to effective and engaging instruction (Duschl & Wright, 1989), and perhaps especially beneficial when teaching higher-order concepts such as complex systems (Levy et al., 2018). Connecting improvisation with teaching is not a new idea (Berliner, 1987; Eisner, 2002; Erickson, 1982; Halverson, 2018; Lampert & Graziani, 2009; Leinhardt & Greeno, 1986; Sawyer, 2004a, b; Sawyer, 2011; Yinger, 1987) as scholars have argued that improvisation can be a model for balancing the structure and flexibility that instruction requires (Beghetto & Kaufman, 2011; Berliner, 2004; Sawyer, 2004a; Sawyer, 2011). To be sure, teaching is in many ways an exercise in improvisation. However, because improv rules do not map neatly onto classroom instruction, teachers spontaneously using an improvisational approach undergo an underground translation process to make improv relevant to their pedagogy.

In this paper we surface this translated model of improv to analyze inquiry-based science teaching in a mixed reality context that supports student-driven learning (Hannafin & Land, 1997). We call our model *instructional improv,* which explicitly synthesizes the rules of improv with student-driven teaching practices to support learning, engagement, and agency (e.g., Danish et al., 2015). While improv is not a new framework for teaching and learning, our instructional improv model uniquely offers researchers a targeted lens for understanding how teachers balance structure and student agency in open, student-driven learning environments that emphasize inquiry and play. It also provides an outline for instructors engaged in teaching science in student-driven learning environments. The instructional improv model focuses on how teachers spontaneously use improv moves to guide student learning while also honoring their emergent contributions, aligning with work that describes the collective inquiry and knowledge-building processes in student-driven learning environments over time (e.g., Tao & Zhang, 2018; Zhang et al., 2018). What instructional improv adds to the literature is a focus on how teachers can organize their teaching to support student learning, engagement, and agency within collective storytelling embedded in science learning.

We built our model of instructional improv through analysis of a case study of an inquiry-based science unit for first and second-graders that used mixed reality technology. We found that in the course of one teacher's (Ms. Jones[1]) spontaneous use of improvisation, she simultaneously honored her curricular goals, recognized student contributions, and offered students agency within learning. In this paper, we center the participation of one student in particular (Zed) and how he came to understand the relationship between bee communication and the location of particular flowers as part of the pollination process. The instructional improv model emerged during our post hoc

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[1]Teacher and student names are pseudonyms

video analysis of classroom interactions. Therefore, we consider the instructional improv model an emergent analytical tool for researchers to make sense of how teachers structure discourse to support student agency and shape learning. In this paper, we show instructional improv in action through an example of a play-based science inquiry activity as part of the Science through Technology Enhanced Play (STEP) project (Danish et al., 2015; Keifert et al., 2017). Our guiding research question is: How can understanding inquiry-based discourse as theatrical improvisation explain how teachers teach in a student-driven learning environment?

## Improvisation as a way of understanding teaching

We define improvisation generally as the art of spontaneous performance that occurs within an overarching framework of rules that guide interaction (Fey, 2011; Halper et al., 1994; Sawyer, 2004a, b). Prior work connecting teaching and improvisation has attempted to use the existing rules of theatrical or musical improvisation as a framework for identifying aspects of effective teaching (Borko & Livingston, 1989; Moore, 1993; Sawyer, 2004a; Yinger, 1987) or as a guide for how teachers might use improv in their lessons (e.g., Lobman & Lundquist, 2007; Sawyer, 2004b). In much of this prior work improv is used as a general metaphor for teaching (Erickson, 1982, Foster, 2001; Mehan, 1979). Improvisation can support teachers in engaging in more open, responsive approaches to instruction as scholars have pointed out that improv shares at least three general qualities with this kind of teaching and learning: (a) a willingness to deviate from planned scripts (Beghetto & Kaufman, 2011; Jurow & McFadden, 2011); (b) keeping instruction responsive to student ideas (Lobman, 2006); and (c) offering students agency in classroom activities (Gershon, 2006). Improvisation can also encourage teachers to rethink their own practice (Halverson, 2018; Vossoughi et al., 2021).

## Improvisational role-play leads to agency and engagement

The benefit of improvisation is perhaps most obvious in classrooms where teachers explicitly introduce drama and role-play as a mechanism for engaging with complex phenomena by taking on a role within that phenomena. In our own work, that might mean learning about how honeybees collect nectar by acting like a bee (Dahn et al., 2018) or how particles produce states of matter by acting like a particle (Danish et al., 2015). In these contexts, dramatic role-play supports disciplinary enjoyment and engagement when learning advanced science concepts (Aubusson & Fogwill, 2006). Dramatic role-play is successful when teachers emphasize student interests (Ainley, 2012), engagement, (Danish et al., 2015), and agency (e.g., Engle & Conant, 2002). When teachers incorporate dramatic role-play within science instruction, activities tend to be improvised (rather than scripted) and promote opportunities for student-centered discourse (Dorion, 2009; Johnson, 1999; Odegaard, 2003; Somers, 1994; Tvieta, 1996).

  In a review of the presence of drama in science education, Odegaard (2003) "consistently highlights findings of high motivation among students, imbued in part by their perceptions of empowerment and ownership during these events" (as cited in Dorion, 2009, p. 2248). These feelings of motivation, empowerment, and ownership are deeply connected to the goal of supporting student agency in science learning. While student agency has not had a unified definition or operationalization across the science

education literature (Arnold & Clarke, 2014), we understand agency to be part of discursive practice in which students drive, develop, or shape what counts as science during classroom lessons. In our role-play context, having agency meant having ownership over learning by contributing in ways that pushed the science learning forward, whether or not additions reflected the science content in the teacher's curricular plan.

### Using improv as a framework for science classroom discourse and argumentation

Even classroom instruction that does not explicitly incorporate drama, can still be viewed through the lens of improvisation to understand the balance that teachers strike between guiding classroom discourse toward learning while also adapting to the interests and ideas of students (Morgan-Fleming, 1999). During lessons, teachers must consider their responses to a wide variety of possible contributions, both those that are relevant to the lesson and those that are not. Teachers plan for how to respond to the array of understandings students bring with them, including those that represent the target content knowledge and those that are based on incomplete disciplinary knowledge.

Research on how to structure science classrooms often focuses on supporting scientific practices through discourse (Duschl & Osborne, 2002; Kelly, 2007; Lemke, 1990; Mehan, 1979). As a practical example, Michaels and O'Connor (2012) present a framework for *talk moves*, which offers suggestions for how teachers can promote productive science talk. Within a discussion, talk moves are matched with the teacher's proximal goals for the discussion, such as asking students to provide evidence to deepen their thinking or rephrase a peer's idea to get them listening to one another. The framework Michaels and O'Connor authored is rational, functional, practical, and comprehensive in describing how teacher moves might support content learning through collective inquiry. However, it does not explicitly address student agency, something we believe to be of central importance in the open, playful learning environments in which we are interested describing.

Instructional improv can expand talk moves by offering guidance on how to combine a focus on supporting discourse in learning through inquiry with student agency. In particular, while talk moves seems to focus on the structure of discussion and what the conversation should be about, we believe instructional improv qualitatively highlights how the conversation should *feel*. Instructional improv emphasizes the subjective experience of engaging in conversation for a specific purpose. The model provides a way to conceptualize the narrative structure of science conversations, thus framing learning as a dialogical art of collective storytelling and as something the children and teacher are doing together. We see the model of instructional improv working alongside recommendations like talk moves to provide a narrative that can further support understanding the purpose of conversations about science.

Instructional improv is not alone in providing this larger narrative about the purpose of science discussions. Many authors have focused on framing science discussions in terms of argumentation (e.g., Bricker & Bell, 2008; Driver, Newton, & Osborne, 2000; Kelly & Takao, 2002). Positioning science discussions as arguments shapes what people think the conversation is for and guides how they participate. Instructional improv provides a complementary narrative to science talk as argument. The science as argument

narrative aligns closely with how scientists actually engage in science (Latour, 1987; Pickering, 1992), and instructional improv is also relevant to how scientists engage in that it highlights collaborative and coordinated efforts of producing something together. In the case we present here the class worked to produce shared explanations and stories of how things work in science. Part of our contribution is that we identify specific improv rules to help explain how teachers are spontaneously organizing discourse in science classrooms to support learning, engagement, and agency in student-driven learning environments. We first describe the context in which our model was developed before describing the instructional improv model below.

### The STEP mixed reality environment

Our case study takes place in the Science through Technology Enhanced Play (STEP) environment. STEP was designed to facilitate science inquiry by assisting first and second-graders in learning about complex science concepts such as the particulate nature of matter (Danish et al., 2015) and the symbiotic relationship between honey bees and flowers (Keifert et al., 2017). STEP encourages teachers to use an open, student-driven approach to learning through inquiry and play in science and uses mixed reality technology to support this student-driven learning. The mixed reality technology was designed to facilitate children's inquiry through pretend play toward understanding the real-life relationship between bees and flowers (Keifert et al., 2017). By using STEP, learners can manipulate virtual objects (e.g., flowers) through actions they take in the real world (e.g., where they walk in the room).

The STEP environment (Fig. 1) uses Microsoft Kinect cameras placed around the room to capture student movement. Computer vision software called OpenPTrack (Munaro et al., 2014) then translates this motion into information which can be used to control aspects of a computer simulation of bees collecting nectar for the hive and pollinating flowers (see http://openptrack.org/education/). As six to 12 students moved about the mixed reality space at a time, each was assigned an avatar bee, and these bees
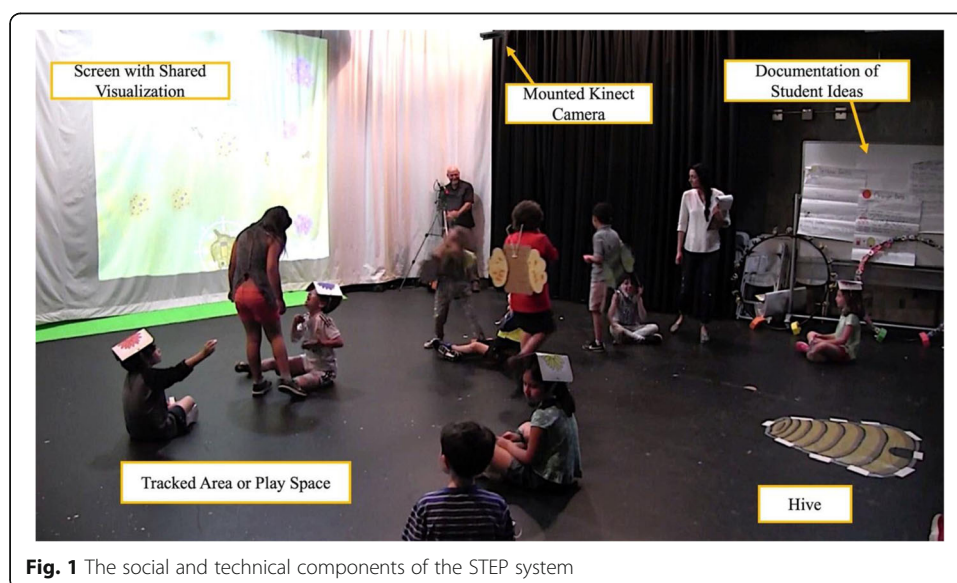


**Fig. 1** The social and technical components of the STEP system

interacted with virtual flowers. All activity was projected on a large screen. Students collaborated to forage for nectar to bring honey back to the hive, communicate with other bees, and incidentally pollinate flowers. As some students interacted with the mixed reality, others observed and shared ideas from the discussion space. The visualization itself was simple. As the students-as-bees moved around, previously hidden flowers would appear, and as their bees landed on the flowers, they had to collect nectar and bring it back to the hive (Fig. 2). The hive on the floor (See Figs. 1 and 2), was an essential part of the play as it was where students returned in order to deposit the collected nectar. Within the hive, other computer-controlled bees would dance to tell the students where new flowers could be found. At the conclusion of the foraging session, flowers that had been pollinated reproduced, resulting in additional flowers appearing close by, while those that were not would die and disappear from the map projected on the large screen.

While we believe the instructional improv framework could be useful in many different learning contexts, its value is highlighted in STEP, which is a student-driven learning environment emphasizing inquiry and play using mixed reality technology. Within STEP students had flexibility to make choices and discover the results of their actions through a playful collective inquiry process. Thus STEP provided a meaningful context for the development of the instructional improv model given that teachers needed to effectively manage student agency and their own science content learning goals to make the environment work.

### Overview of STEP lesson design

Participating teachers and researchers co-designed five STEP lessons that were approximately 45 min each. Improv was not part of our conversations prior to or during STEP



**Fig. 2** Students playing as bees collected nectar from flowers and brought it back to the hive

lesson design and implementation. Each STEP lesson had overarching goals driven by specific inquiry questions yet were open-ended enough to allow for play. For example, the first STEP lesson began with a simulation of bees landing on flowers because this was something familiar. We encouraged students to walk around the space as their avatar bees and consider what bees did when they landed on flowers (i.e., the bees had nectar bars that would fill up as pollen emanated from flowers). This part of the STEP simulation was important because first and second-grade children typically know that bees have something to do with flowers and honey, but little beyond that. Overall, STEP aimed to help students explore and recognize the way that bees' nectar collection activities rely upon communication between bees through a waggle dance and also unintentionally promote flower pollination (see Table 1 for lesson activities and inquiry goals). Though open and exploratory, the curriculum loosely aligned with NGSS standard *2-LS2, Ecosystems: Interactions, Energy, and Dynamics* and attended to particular crosscutting concepts like patterns and system models to help students better understand complex phenomena (NGSS Lead States, 2013). Our case study focuses on how students unpacked the specific details of what bees need to do to communicate to collect nectar and support the hive.

## Methods

Our research team has previously demonstrated that STEP supported students in learning target science content (Danish et al., 2015), shown how different play structures in STEP supported collaborative learning (DeLiema et al., 2019), illustrated how STEP foregrounds the role of the body in student agency and sense making about science (Keifert et al., 2017; Keifert et al., 2020), and discussed the challenges associated with bringing mixed reality to formal K-12 educational settings (Keifert et al., 2017). However, prior analyses have not fully articulated how teachers pedagogically supported playful inquiry during STEP. Here we extend and refine design arguments from our prior work (Dahn et al., 2018) to focus on how instructional improv can help us understand how teachers face the tension in balancing playful inquiry with structure.

**Table 1** Description of Bee Unit Activities and Learning Goals

| Activity | Learning Goals |
| --- | --- |
| **Giant Flower**: Students collect nectar from a single large flower visible from the beginning of the activity. | · Introduction to the difference between nectar and pollen<br>· Introduction to the goal of bees (i.e., to collect nectar and bring it back to the hive) |
| **Bee Foraging Play**: Students as bees find hidden flowers and collect nectar to bring back to the hive. | · Bees need to forage from multiple flower patches<br>· Different patches have different quality nectar<br>· Different patches are different distances and directions from the hive |
| **Waggle Dance Play**: The students invent their own waggle dance to tell each other where flowers are. Next the students watch the computer-controlled bees do the waggle dance to tell them where hidden flower patches are. | · Bees must communicate the direction, distance, and quality of flower patches to their fellow bees<br>· Bees need to organize themselves to send more bees to better flower patches<br>· Not every bee should go to the same flower patch to avoid potential disaster |
| **Pollination Play**: Some students pretend to be flowers and others pretend to be bees. Flowers that are not visited multiple times by bees carrying the right type of pollen die. | · Bees pick up pollen by accident and distribute it to other flowers as they forage for more nectar<br>· Flowers depend on pollination to produce offspring |

Although tensions are always present in classrooms, we believe they especially surface in student-driven and playful learning environments such as STEP.

### Participants

Student participants were from a mixed-age first and second-grade classroom (ages 6–8) at a university-affiliated elementary school where racial and ethnic diversity is a core part of the school culture (i.e., the racial/ethnic breakdown is approximately 36% white, 20% Latinx, 9% Asian, 7% Black, 12% Latinx/white, 5% Asian/white, 3% Black/white, and 8% identifying with other races/ethnicities). Here we focus on one teacher, Ms. Jones, and her students ($n = 26$), though a total of 76 children spread across three classrooms and three different teachers engaged with STEP (42 first-graders and 34 s-graders; 51% girls).

Ms. Jones was familiar with inquiry-based teaching and regularly incorporated student voice into her teaching practice. Of the three teachers we observed, we noted a high degree of student agency in Ms. Jones's classroom and noticed that her instruction felt naturally improvisational. Additionally, because we found that there was a statistically significant difference between all pre and post-test measures of science content knowledge (MD = 5.38; t $(75) = -15.47$, $p < .05$) (including ideas about bees' foraging cycle, communication process, and pollination), yet no significant differences in test scores among classrooms, we reasoned that we could focus on Ms. Jones so that we could qualitatively unpack in detail how learning happened in her classroom using instructional improv as an analytical tool to drive our analysis. To reiterate how instructional improvisation came to be, though we showed Ms. Jones how the mixed reality STEP environment worked and suggested she follow the students' emergent goals during the co-designed lessons, we did not explicitly talk about using improvisation in her pedagogical approach.

### Data sources and analytical approach

#### Video of classroom lessons

All classroom interactions were video recorded from two angles, resulting in over 7 h of video footage. Our unit of analysis focused on the micro turn-by-turn interactions between students and teachers situated within a whole class participation framework (Goodwin, 1990; Goodwin, 2007). In tracing each turn at talk and/or action, we were interested in what the teacher said and did and how a student (or students) responded to the teacher's initial talk and/or action. Therefore, each unit of analysis (as a series of turns) focused on the teacher's move and subsequent student responses to that move.

To analyze the video with an eye to both the broader instructional unit and immediate context of turns at talk and action, we reviewed our field notes to aid our video viewing and then created activity logs with time indexes of major instructional events, noting particular patterns of interest for interaction analysis (Jordan & Henderson, 1995). Our initial viewings were guided by our goal to understand, broadly, how the teacher supported inquiry-based learning in the STEP environment. We then revisited the video collectively, looking closely at the micro interactions within the major instructional events to iteratively develop and refine conjectures about how students learned within the classroom ecosystem (Erickson, 2006). Three of the four authors

were present for all sessions and thus had a great deal of familiarity with how class-room interactions evolved. Importantly, though the science lessons were co-developed with researchers and teachers and all had a close working relationship, improvisation as a framework for instruction was not explicitly part of the study until post-hoc video analyses were conducted. The first author has a theater background and in the course of video analysis, developed a conjecture about how improvisation might help explain the nature of the relationship between the teacher's instructional turns, play, and student agency. We then began a more focused analysis of how the teacher actions might be aligned with improv using both theater and teaching literature. In this pass, we used a constant comparative analysis (Glaser, 1965; Glaser & Strauss, 1967) by looking at subsets of video data, writing memos about what we noticed in relation to improv moves, and further developed our understanding of how the moves translated to this inquiry-based context to support student agency and learning.

Though we saw improv as a framework consistently across the five lessons in the unit, we chose particular episodes from two lessons to pursue in depth for analysis here because Ms. Jones and her students were very playful during these episodes. Ms. Jones uniquely practiced playfulness with her students by remaining open to new ideas, being spontaneous, and working to sustain the playful roles of being bees throughout the activity (i.e., we noticed that in contrast to other STEP teachers who maintained their formal teacher roles, Ms. Jones entered the tracked space and interacted alongside the students as a fellow bee within the simulation (DeLiema et al., 2019)). She also remained playful throughout the STEP project by displaying joy and excitement as students played and explored as bees. Additionally, in these episodes, the students exercised agency and there were clear outcomes tied to learning the target science. The excerpts that make up the episodes include the most salient aspects of improv, learning, and agency to tell a cohesive story. In our video analysis we worked both backwards and forwards within each episode (e.g., Enyedy, 2003) to create and refine conjectures about how Ms. Jones facilitated interaction in a manner that was consistent with what we were understanding about improv. However, we knew that just finding examples of how Ms. Jones worked in an improvisational manner was not all that interesting or consequential for inquiry-based teaching and learning. Therefore, using additional tools of interaction analysis (Jordan & Henderson, 1995) to review these episodes, we transcribed particular points of interest from our activity logs, asking ourselves not only how the scene felt like improv but also how each teacher move might have played a role in supporting student agency and learning. To answer this question, we attempted to establish how claims and explanations that students made about the behaviors of the honey bees might have been curtailed or expanded in response to the teacher statements and interactional moves that mirrored improv. We looked for evidence of learning the same content-related concepts that we examined in our pre-post interviews such as those about bee communication and pollination (though not central to our analysis here, these pre-post interviews included open-ended questions that asked students to explain and show how bees communicated via a waggle dance and how pollination worked). Through this process of our collective analytical work, we found that improv was at the heart of how the teacher successfully coordinated discourse in ways that supported student learning, engagement, and agency. What we eventually called the teacher's instructional improvisation in this case seemed especially concerned with telling a story about the science content.

### Lesson plans and teacher interview

As we reviewed the video, we also cross referenced our analysis with Ms. Jones's lesson plans to keep the broader context at top of mind and so we could understand how her actions deviated or aligned with her written plans. We note some of these differences as appropriate in our findings. Additionally, we conducted an interview with Ms. Jones after we conducted our video analyses to uncover her experience and get her take on our interpretations. We prompted Ms. Jones to reflect on her practice, asked how STEP supported the inquiry process, and specifically queried how she viewed improv in relation to her teaching. Some of the questions we asked Ms. Jones were: In your teaching in general, how do you experience the tension between getting students to learn academic content while at the same time following their ideas and interests during lessons? Have you ever thought about using improv in your teaching before to address that tension? Which of the specific improv moves we outline in our analysis –– always agree, etc. –– do you think are most relevant to your instructional practice in general? Which were most helpful in STEP? We transcribed the interview and pulled out key excerpts in which Ms. Jones articulated how she shaped learning in STEP and how she saw her choices in relation to improv as an insider check on our instructional improv model.

### Instructional improv to support inquiry-based science learning

To introduce instructional improv, we (a) name the rules that guide the model; (b) describe the improv rule in the context of an imaginary theatrical scene where two strangers are trapped in a dungeon; and (c) describe how instructional improv translates the rule to the specific science inquiry context relevant to our study (i.e., how a teacher could help students learn about how honey bees collect nectar). For the classroom context, we focus specifically on how the teacher helps students understand how bees organize themselves to effectively collect nectar while accidentally pollinating, a particularly challenging concept that represents complex systems thinking. We draw from a collection of improvisational rules (Fey, 2011; Halpern et al., 1994; Halverson, 2018; Sawyer, 2004b) and modify them to map them onto instructional practices. The rules we highlight below as part of our model are: (1) *tell a story*, (2) *no mistakes, only opportunities*, (3) *always agree*, (4) *yes, and …*, (5) *make statements*, and (6) *the needs of the ensemble are greater than the individual*. These rules overlap and can be used simultaneously in practice, though we describe each separately. After detailing our instructional improv model, we move into the second half of our findings to illustrate instructional improv in the context of our STEP data.

### Tell a story

The first rule of our model emphasizes the need for actors to work collaboratively to construct a coherent story. In improvisational theater, actors typically identify a topic for their story by soliciting suggestions from an audience and then developing the story in collaboration. For example, actors might ask for a context, and a person in the audience might say, "Teamwork!" While the actors do not yet know where the story will end, they have a shared starting point.

In a classroom context, learning also means developing shared understandings as students work to actively make sense of the world (Metz, 1997). The metaphor of telling a shared story highlights how the teacher helps students connect their ideas to produce a unified explanation of a phenomenon (Schank, 1995). A focus on a collective explanation challenges students to resolve their theoretical disagreements while also providing them with an explanation that they can then appropriate for individual pursuits (Scardamalia & Bereiter, 2006). It is important that teachers be responsive to student contributions to help further the co-constructed storyline and to support science discourse, including getting students to think with each other by voicing agreement or dissent, adding on, and explaining what others mean (Michaels & O'Connor, 2012).

### No mistakes, only opportunities

A second rule is that there are no mistakes, only opportunities. This means that if an actor begins in an unexpected way, it is the scene partner's job to pick up the offer rather than negating and framing the initiation as a mistake. For example, in response to the "Teamwork!" suggestion above, one actor could open the scene with, "We have to find a way to get out of this dungeon, Nelson." Even if "Nelson" had a completely different idea for the scene (e.g., playing beach volleyball), he should respond by saying something like, "Yes, there must be a way out." Although the partners were not on the same page before the scene began, unexpected happenings and mistakes are part of the collective work of improv.

This improv rule applies in a classroom context when the teacher views a wrong answer as a way to illuminate the child's current conceptual understanding and outline the limits of that understanding. Teachers ought to build off student intuitions so that students can integrate new knowledge into what they know and amend their current understandings (Smith et al.,1994). For example, one of the goals of our study was to teach students the importance of the waggle dance communication system to collect nectar for the hive. A student might say, "The queen tells the bees where to collect the nectar in the hive!" Instead of correcting the statement immediately and pointing out that forager bees self-organize using a dance, a teacher integrating the no mistakes rule would take the opportunity to test the idea. The teacher could respond, "Let's try it," and set up a role-play scenario in which students pretending to be bees could collect nectar at flowers only after the queen (played by the teacher) instructed them where to go. Students playing bees would need to wait in line for the queen to tell them individually where to go, causing a hive traffic jam. Through this simulation, students would come to realize on their own that the queen cannot possibly dictate the nectar collection system.

Through instructional improv, a teacher reorients misconceptions as resources for learning and expanding. The no mistakes rule of improv aims to refine children's ideas rather than erasing and replacing them (Smith et al., 1994) and can help teachers to avoid overscripting the interactional sequence in advance (Sawyer, 2004b). The no mistakes rule supports best practices in science discourse because by exploring misconceptions as they arise, students can confront precisely what makes them problematic (Michaels & O'Connor, 2012), not just reject them because they represent the wrong answer.

### Always agree

The third rule of improvisation in our model (and often the first rule of theatrical improv) is to always agree. Aligned with the rule of *no mistakes*, *always agree* means you need to support the direction your partner takes a scene. To expand on the example incorporating the dungeon, the first partner could say, "This dungeon is creepy. Thank goodness I brought these spoons to dig us out of here." An appropriate response could be, "I suppose we won't be needing this shovel then." By agreeing with the premise that you are stuck in a dungeon together, you are helping the scene progress. If you instead negate your partner's idea and say, "We're not in a dungeon, we're at the beach," you have broken the second and third rules.

In learning contexts, agreement does not mean that the teacher should always agree that everything students say is correct. Agreement closely aligns with teacher discourse moves in the form of revoicing (O'Connor & Michaels, 1993). In revoicing the teacher acknowledges individual contributions by restating a student's idea to the class, transforming the idea slightly, and handing the floor back to the student. Through revoicing, teachers can position students to take on roles and identities. In our pollination vignette, if a student said, "When the bees are flying around, they spread the pollen all over!" the teacher should agree with the student response by acknowledging the contribution, "The pollen does *look like* it is being spread around––is that what you mean?" to ask the student to confirm or disconfirm the teacher's inference before moving forward with the lesson.

### "Yes, and …"

The fourth rule we appropriate for our improvisation model is to always say "yes, and … ," meaning you should add to the story. For example, an actor might continue the dungeon scene by adding, "Okay, here's your spoon. Let's start digging." The intentionality of this move gives the actors something new to accomplish together. If the speaker just ended with his agreement of, "Yep, so this is it," he would be agreeing but not adding much, therefore placing all responsibility on the scene partner.

In classrooms, "yes, and …" positions teachers and students as co-constructors of knowledge, standing in contrast with traditional discourse structures like Initiate-Respond-Evaluate (Cazden, 2001; Mehan, 1979). While I-R-E is sometimes appropriate, if teachers only evaluate student contributions as right or wrong, they are not pushing the limits of student understanding. To test these limits, a teacher can pick critical points to "yes, and …" by making connections between curricular ideas such as how bees incidentally pollinate as they collect nectar at flowers. By agreeing with a contribution and adding on, the teacher adds complexity after she validates the idea, therefore giving the student agency and collective ownership of classroom science knowledge while continuing to push for a more nuanced explanation. "Yes, and …" also helps us see how teachers to connect ideas to each other.

### Make statements (or ask questions that elicit statements)

The fourth rule of our model is about making statements, meaning that improvisors should be part of a solution and not just create problems. If an actor in the dungeon had asked, "Why are we stuck here?" they would be placing responsibility on their

partner to come up with the premise for the scene. A statement (or offer) is any action, dialogue, or strategic addition that advances the scene (Halpern et al., 1994) and so to add to the dungeon scene in which the actors are digging themselves out with spoons, one might make the statement, "Thankfully this wall seems to be made of ice cream. Yum."

To implement make statements (or ask questions that elicit statements) rule in a classroom, teachers can make statements to elaborate on student contributions or ask questions to strategically guide the inquiry process and push the collective story and lesson forward. Two types of questions that teachers often use already in science classroom discourse are a particularly good fit for our model: 1) asking for evidence or reasoning and 2) challenging thinking or providing a counter example (Michaels & O'Connor, 2012). Asking, "Why do you think bees communicate with each other?" (elaborate reasoning) or "What makes you think the direction of the waggle dance tells other bees where to go?" (asking for evidence) helps make thinking visible and available as an object for reflection. Asking questions like, "Would the queen bee really be able to talk to all 10,000 forager bees to tell them where to go?" (challenge) or "Wiley thought that the forager bees communicate directly to each other; would that work?" (counter example) can spark learning through cognitive conflict to help students critically reflect on their ideas and assumptions (Ginsburg & Opper, 1988; Posner et al., 1982).

### The needs of the ensemble are greater than the individual

This final rule connects back to the theoretical framework provided by the first two: in order to tell a story and honor that there are no mistakes in improv, it is necessary for actors to put the needs of the ensemble over their own as individuals. Rather than attempt to steal the scene or say a line for a quick laugh, actors need to consistently think about how to react to each offer as a further elaboration of their co-constructed storyline with an emphasis on the cooperative nature of interaction. For example, in response to the dungeon wall being made of ice cream, an actor should be thinking, "What can I do to contribute to this scene about being stuck in an ice cream dungeon?" If actors listen and find ways to incorporate all the ideas into the storyline, the story is richer. Improv is not really about individuals, and the same is true about the classroom when we talk about discourse. Successful improvisation in both spaces is evidenced through collective storytelling.

The ensemble rule highlights the social aspects of learning. In instructional improv the students and teacher work together to create a shared understanding of the world that is aligned with current conceptualization of the phenomenon in question. This final rule for our model helps clarify other rules and sometimes takes precedent during interaction. For example, while it is important in improvisation to agree, strict adherence to the rules of agreement presents challenges. In general, student ideas should be validated, but teachers may have to subtly negate or ignore an off-topic suggestion for the good of the group to prevent entrenched misunderstandings.

Furthermore, the rule of prioritizing the ensemble is particularly important for dealing with diverse needs and perspectives in a classroom of students. For example, if the group is engaged in a seemingly productive conversation about the difference between

pollen and nectar, it might seem tangential and distracting if an individual student asks, "What if a predator came and killed all the bees?" A teacher following the ensemble rule could respond, "That is an interesting question––let's come back to that later. Now Mila was saying that the pollen is what the bees carry from flower to flower and the nectar is what they carry to the hive. Do we agree with her statement? Why or why not?" While this interactional move seems to conflict with the improv rule of agreement, given the constraints of a classroom environment, the teacher sometimes needs to subtly negate a student's suggestion in order to move the collective forward.

## Findings
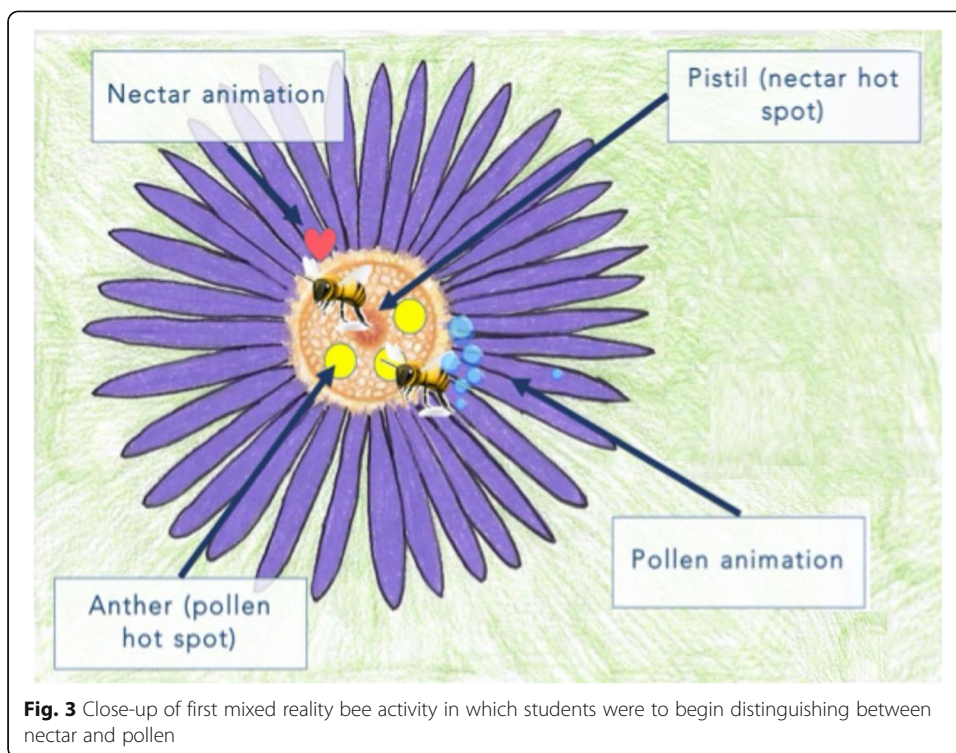### Instructional improv as a framework for teaching and learning
To show how instructional improv in our data below, we present analysis from two episodes as examples of how instructional improv in teaching led to student agency in science learning. Episode one comes from the first lesson in which Ms. Jones had two curricular goals for students: (1) to become acquainted with the technology and (2) to understand that bees aim to collect nectar at flowers and as they do so, they get pollen on their hind legs. Episode two comes from the fourth lesson in which Ms. Jones planned for students to learn about how honey bees communicate via the waggle dance to organize the hive to forage for nectar.

### *Setting the scene for Episode 1*
Bees do not deliberately pollinate flowers. Pollination occurs in passing as bees collect nectar in flowers and travel from place to place. The STEP simulation represented the distinction between nectar and pollen through color and animation: when a student bee passed over a large orange dot (representing nectar), animated hearts would rise up from the nectar spot indicating the quality or "yumminess" of the nectar (1 heart representing "so-so" nectar, 2 hearts, "yummy" nectar, and 3 hearts, "super yummy" nectar). When a student bee passed over a large yellow dot (representing pollen), animated sparkles would appear and pollen appeared on the bee's hind legs (Fig. 3). Although all students were not clear with the distinction between nectar and pollen at first, it was important they came to understand why bees communicate (i.e., to collect nectar) and connect bee communication to how pollination occurs (i.e., bees pollinate by chance as a result of collecting nectar).

### *Episode 1: improvisation as a method to introduce science content through play*

**Scene 1. A question sets science content in motion** In Excerpt 1 we join our students-becoming-bees as they entered the mixed reality space for the first time. After The Magic Hoop (a decorated hula hoop) was put in place just outside the mixed reality space, students were eager to walk through it to "become" bees. As Ms. Jones called students individually, Jesse walked through the hoop. As Jesse moved into the mixed reality space and hovered over a flower, animated hearts rose from the orange nectar and sparkles radiated from the yellow pollen. When this happened, he said, "Oh my gosh," and a few students sitting in the discussion space (labeled as the hive, indicated by yellow yoga mats placed outside of the mixed reality space) repeated his shocked

**Fig. 3** Close-up of first mixed reality bee activity in which students were to begin distinguishing between nectar and pollen

reaction. Ms. Jones asked the group, "What do you see?" to prompt students to elaborate. Jade explained that she thought Jesse ate nectar. After Jesse stumbled back and said, "Woah," his classmates laughed. Jesse then danced over the flower, which made students laugh again. When he finally did exit the mixed reality space, he called "I pollinated it" from his spot in the discussion space.

Excerpt 1
*Episode 1, Scene 1*

| Turn | Speaker | Talk | Action |
|---|---|---|---|
| 1 | Jesse | Oh my gosh [Gasping] | *Enters the mixed reality space* |
| 2 | Other students | Oh my gosh [Gasping] | *Observing Jesse* |
| 3 | Ms. Jones | What do you see? | *Ms. Jones leans into the mixed reality space* |
| 4 | Jesse | | *Stops on hive* |
| 5 | Jesse | | *Walks forward from hive while looking at screen* |
| 6 | Jade | You just ate the nectar! | |
| 7 | Jesse | Woah | *Stops on orange dot* |
| 8 | Other students | [Laughter; additional conversation] | |
| 9 | Jesse | I pollinated it | *Jesse calls out from discussion space as next student explores mixed reality space* |

When viewing Excerpt 1 through the lens of instructional improv, we see that Ms. Jones responded to the gasps with an offer to advance the scene by asking, "What do you see?" in turn 3. Her offer was presented in the form of the improv rule, *makes statements (or ask questions that elicit statements)* because instead of redirecting

students to focus on the task at hand (i.e., quickly getting a chance to find their bee on the screen), she acknowledged and furthered the class reactions (of gasping). In this case, the *makes statements (or ask questions that elicit statements)* rule frames Ms. Jones's questions as improvised turns at talk that encouraged students to continue building on their excitement while discovering and exploring the science phenomena. Her improv move offered Jesse agency to linger in the mixed reality space and excitedly explore what his bee avatar could do when it hovered over flowers (i.e., collect nectar and pollinate). Ms. Jones's question led to turn 6 in which Jade explained that Jesse as a bee was getting nectar. Jade's public hypothesis of what Jesse the bee was doing was an opportunity for the class to discover the science content of what bees do when they visit flowers. Ms. Jones's improv continued to have a desired effect in turn 9 when Jesse suggested, "I pollinated it," referring back to what happened when he was in the mixed reality space. Ms. Jones's improv move elicited student statements that were explicitly tied to the day's content objectives.

Ms. Jones's question in turn 3 was also an example of the *no mistakes, only opportunities* part of instructional improv because exploring the science content was not explicitly written into this part of her lesson plan. Here, the *no mistakes, only opportunities* rule highlights both the type of teacher discourse that sustained the excitement of learning while simultaneously guiding that excitement toward discussion of the science phenomena. The beginning of Ms. Jones's lesson plan indicated that students would enter "one by one to find themselves on the screen," but the science content was not part of the written lesson until after all students had a chance to explore using the technology. However, in responding to what happened in the moment, Ms. Jones made a choice to deviate from her script when Jesse accidentally triggered the giant flower in the mixed reality space. In response to the unexpected happening, she asked a question motivated by her decision to be responsive to student contributions and relinquish control to let Jesse comment on his exciting discovery. Using the instructional improv model helps to explain at the interactional level how students distinguished the science content through inquiry. The effects of Ms. Jones's improv move is that by acknowledging the "Oh my gosh" contributions in turns 1 and 2, students were given the floor to share their observations and had agency to drive the lesson toward what they found most interesting, thus shifting traditional classroom dynamics of power and control from the teacher to students.

Ms. Jones's improv move set the tone for this very first lesson in the STEP space, leading students to continuously make exciting observations and discoveries in the mixed reality space. In this particular instance, her move led Jade to make a contribution that advanced the scene and connected to the science-centered learning objective for the day when she excitedly said to Jesse in turn 6, "You just ate the nectar!" The effect continued when Jesse said, "I pollinated it!" a few turns after exiting the mixed reality space. Ms. Jones's choice to let go at the beginning of the lesson set the day's science topic in motion while affirming class engagement in learning science. Stepping back and allowing students to co-construct the narrative about nectar collection and pollination in the first few minutes of the very first lesson appears to have set the tone for the joint inquiry that continued to occur throughout lessons in the STEP space.

**Scene 2. Instructional improv helps students build on initial understandings**
Excerpt 2 presents an interaction toward the end of the same first lesson during which five students played in the mixed reality space as other student audience members called out what they noticed from the discussion space. In this scene, we continue to utilize the instructional improv model to show how teacher discourse sustained engagement toward doing science. As students talked about different strategies for filling up the hive, Ms. Jones pointed out that Adam got nectar from the flower and then asked everyone what he was filling it with. Several students yelled, "Nectar!" and Ms. Jones asked, "the honey?" Next, students took over the lesson––Jesse shifted his attention to the sparkling animation and commented that maybe it represented pollination. Jade began presenting her own observation about pollination, but her thought was cut short by Jesse's elaboration, "When the little dots are coming out of you that means you're pollinating." At this point, Ms. Jones responded with an exaggerated "Oooh," and Zed explained that he "gets it," that when hearts come out of the flower on the screen, that means bees get nectar to fill the hive.

Excerpt 2
*Episode 1, Scene 2*

| Turn | Speaker | Talk | Action |
|---|---|---|---|
| 1 | David | Maybe you can fill some | |
| 2 | Researcher | Oh, Adam just filled some | *Adam fills the hive with nectar* |
| 3 | Ms. Jones | Adam got some. Dylan's going … | *Dylan walks back to hive* |
| 4 | David | You have to fill it and then bring it back to the hive | |
| 5 | Ms. Jones | What are you filling it with? | |
| 6 | Several students | Nectar! | |
| 7 | Ms. Jones | The honey? | |
| 8 | Jesse | No | |
| 9 | Ms. Jones | No honey? | |
| 10 | Jesse | Oh, maybe that's the pollination you did! The- | *Leans in from discussion space* |
| 11 | Zed | Oh, pollen! | *Points to screen from discussion space* |
| 12 | Jade | Oh, I thought of something. If you like go into there and fill up a lot of nectar | *Points to screen from discussion space* |
| 13 | Jesse | When the little dots are coming out of you, that means you're pollinating | *Gestures toward the screen from discussion space* |
| 14 | Ms. Jones | Oooh | |
| 15 | Zed | Oh, I get it! | *Stands up to enter the space* |
| 16 | Ms. Jones | Sit down, sit down. Use your words, use your words | *Gestures for Zed to sit down* |
| 17 | Zed | I get this! I get this! So- | *Sits down* |
| 18 | Ms. Jones | What do you get? What do you get? | *Crouches down toward Zed* |
| 19 | Zed | Um, the, when, if you, if hearts come out that means your, your, your pocket fills up with nectar and then you bring it from the–out and then and then a heart comes up and that means you fill the, the bees are filling the hive with nectar | *Gestures toward the screen throughout his explanation* |
| 20 | Ms. Jones | Oooh there was some good observations that you just had right there | |
| 21 | Many students | [Overlapping talk] | |

From an instructional improv lens, in turn 3 Ms. Jones *agreed* with the contributions by broadcasting student actions to the group––"Adam got some. Dylan's going [to get some nectar]." In response, one student provided a public explanation of the broadcast in turn 4, "You have to fill it and then bring it back to the hive." By following the *always agree* improv rule and positioning embodied actions as valuable forms of participating, Ms. Jones validated student actions as legitimate parts of the science learning. Once again, the instructional improv model illustrates how Ms. Jones's discourse in the interaction led to students continuously and actively exploring concepts of bee and nectar collection.

In turn 5 Ms. Jones asked, "What are you filling it with?" and the students responded, "Nectar!" yet in turns 7 and 9 she made an interesting shift by asking, "the honey?" to contradict the initial (correct) response. In terms of our model for instructional improv, her move represents the rule, "ask a question that elicits a statement," since she made a new contribution with the purpose of advancing the lesson forward. While this misunderstanding was not planned for in her written lesson plans, students were using the terms nectar, pollen, and honey interchangeably, although they mean different things. Ms. Jones could have told the students they were correct when they chorally responded, "Nectar!" however, she made a statement that conflicted with their accurate response in order to prompt further reflection and cognitive conflict to deepen the learning process. The *ask a question* rule captures the playful nature of Ms. Jones's actions and shows how her question sustained student agency and power so that they could explain the science in their own words.

The result of Ms. Jones's improv move of asking, "the honey?" in turns 7 and 9, was three distinct student responses in relation to the target science––two about pollen and one about nectar. In turn 10, Jesse made a conjecture that it was pollen and not nectar (and Zed agreed); in turn 12, Jade made a causal connection between particular locations on the flower and what bees collect (nectar); and in turn 13, Jesse used the animations as evidence to differentiate between the hearts of nectar and the dots of pollen. Most importantly, Ms. Jones's *question that elicited a statement* helped others notice and make the distinction between pollen and nectar as evidenced by Zed's repeated, enthusiastic exclamations that he "gets it" (turns 15 and 17) and student audience members' overlapping talk about the science content (turn 21). Ms. Jones's question led to student agency to publicly express understandings about the target science. Furthermore, her enthusiastic improv supported their joyful reactions toward getting to do the work of science. This reaction was made visible as students physically leaned into the mixed reality area with their bodies from the discussion space, and Zed literally jumped out of his seat to contribute to the discussion in turn 15.

### Setting the scene for Episode 2

When a forager honey bee finds a flower patch, they collect nectar and then need to tell the other bees about the flower patch they found. They do this by doing a waggle dance within the hive which conveys the direction and distance to the flower patch as well as the quality of the nectar it contains. The longer a bee dances, the more likely it is that other bees will see it dance and go to the flower it was advertising, a rather

different approach than what humans might use, and thus a challenging concept for many students to grasp.

### Episode 2: instructional improv leads to co-construction of science learning

In the lessons leading up to Episode 2, the students discussed general bee communication and invented ways to tell each other where the high-quality flower patches were located. Children-as-bees would fly out in a virtual field/flower patch, reveal hidden virtual flowers, and collect nectar. They would then fly back to the hive and tell a partner bee (who had been outside of the room) where they should go to find a good flower. Ms. Jones asked students to figure out how to communicate the direction, distance, and quality of nectar for flower patches to their partner bees without using words. In response, the students-as-bees invented all sorts of gestures and dances to help their friends find "super yummy" nectar including foot taps, giant leaps, and outstretched arms.

**Scene 1. Student agency and joy in instructional improv** Prior to Excerpt 4, students had just watched two waggle dances. When they went to search for the flowers, they discovered that the flowers they were supposed to find in the field were not where they expected because they returned to the literal space on the floor where they had seen the dance rather than treating the dance as a set of instructions of where to fly starting from the hive. As part of the design of the mixed reality, birds as predators were obstacles that prevented bees from foraging for nectar safely. During the lesson, Zed, one of the children playing a bee, was eaten by a bird and became a "ghost bee" that could not collect any nectar. The "ghost bee" feature was an intentional design choice we made to start conversations about bee communication and what actually happened to bees in the wild.

   The predator killed Zed at the moment when Ms. Jones was trying to have the students talk about the situation and an important point of the lesson––why the flower was not in the corner as everyone predicted. Rather than ignore Zed's death however, Ms. Jones adapted with what happened and acknowledged his untimely demise. She told Zed to lay down on the floor and play dead. He did, but of course it is not much fun to lay down, so Zed revived himself and flew away. (Because Zed was on the floor, the sensors lost track of him, and when he stood back up he was assigned a new avatar as a living bee and so according to the screen, he was, in fact, "alive" when he stood up again.) Ms. Jones playfully interacted with Zed for a brief time as other students picked up on the main point of the lesson again. Adam yelled from the discussion space, "There is no other flower, Jesse!" Ms. Jones realized that Adam had finally accepted that there was no flower in the corner and steered the lesson to her objective using his observation as her cue. She asked, "Why is there no other flower, Adam?" in turn 23. Adam offered an explanation that there was no information from when the bees danced in the hive that there would be a flower in that part of the field. What the instructional improv model captures in this scene is how Ms. Jones managed both the playfulness and enjoyment of Zed's bee death while also moving the larger classroom discourse towards science learning goals.

Excerpt 4
*Episode 2, Scene 1*

| Turn | Speaker | Talk | Action |
|---|---|---|---|
| 1 | Student | Guys, not near the sun! | |
| 2 | Jesse | Go to the sun! | |
| 3 | Dylan | Go to the red flower, David! | *A predator flies across the screen* |
| 4 | Jesse | David! | |
| 5 | Zed | Ah, I died! | |
| 6 | Zed | I died! Did you see that? | |
| 7 | Ms. Jones | What happened? | |
| 8 | Zed | The, the eagle came, and I died! | |
| 9 | Ms. Jones | Oh, lay down | *Gestures for Zed to get down on the floor* |
| 10 | Ms. Jones | Lay down | *Repeats gesture for Zed to get down on floor* |
| 11 | Zed | Oh | *Lays down on floor* |
| 12 | David | I can't find it | |
| 13 | Ms. Jones | Zed's dead | |
| 14 | Zed | | *Begins to lift his head* |
| 15 | Ms. Jones | Stay there, stay there, don't get up | *Zed stays on ground* |
| 16 | Jesse | David, go to the sun! | |
| 17 | David | I tri- I am! | |
| 18 | Ms. Jones | So is there a flower- | |
| 19 | Zed | | *Stands up* |
| 20 | Ms. Jones | Nope, sit down. You're dead, lay down. | *Playfully grabs Zed's hand, gestures for him to lay down, laughs* |
| 21 | Zed | No, look it, no look it. I'm still alive! | *Notices his avatar is alive, pulls away from the teacher, runs to left side of the screen* |
| 22 | Adam | There is no other flower, Jesse! | |
| 23 | Ms. Jones | Why is there no other flower, Adam? So why, why isn't there a flower up there? | |
| 24 | Jesse | There's no information that, from the last time we did it, that there was a flower up there | |

Excerpt 4 highlights the balance between student agency and learning as students tried to understand where the missing flowers were. Zed's death due to the predator that flew across the screen in turn 3 was a distraction from the teacher's current plan, yet she did not position his demise as a mistake. We use the instructional improv model to highlight the tension between agency and learning, specifically using improv rules that define how Ms. Jones responded to the distraction while still engaging students in science discourse. Ms. Jones reframed the *mistake as an opportunity* as she *agreed* with Zed's proclamation of "I died" and responded with a *yes, and …* move in turns 9 and 10 by telling him to "lay down" since he was a dead bee. In responding to Zed's offer with agreement in a playful way, she established that the contributions and ideas that students offered, no matter how seemingly tangential, drove the collective science inquiry.

In broadcasting "Zed's dead" in turn 13, she made Zed's play a part of the legitimate class science talk, and Zed was therefore able to participate in ways that made sense to him.

Ms. Jones worked to balance student agency and learning as she went back and forth between different improv moves. In turns 18 and 23 Ms. Jones pivoted from using *yes, and …* moves in her playful interaction with Zed to *putting the needs of the ensemble over the individual* and *telling the instructional story* when she directed her attention toward the missing flower in question. Although playing with the idea of Zed as a dead bee was fun, in turn 23, Ms. Jones instead focused on the target science learning when she *asked a question that elicited an important statement* from Jesse. She asked why there was a missing flower, which directly advanced the science learning connected to how bees translated information about flowers to their dance. To clarify, in this scene, the flower students were looking for wasn't where they expected it to be because when they translated the dance from inside to outside they had a different starting point. Out in the field, of course, bees always start at the hive and so in the STEP space the flower was not in the same literal place on the floor when inside and outside the hive were projected on the screen. This information about waggle dance starting points helped students understand how the complex system of honey bee pollination works because it is a critical part of how bees communicate to the hive at large. Due to Ms. Jones's pivot to focusing on the ensemble rather than just Zed, students began to construct a joint explanation of why the flower was not where they thought it would be, which supported how they conceived of bee communication in the hive.

**Scene 2. Supporting multiple, simultaneous narratives through instructional improv** In Excerpt 5 Ms. Jones again reiterated to students that a bee danced from a spot and ended up at a particular point on the floor while in the hive, but when they went to that point on the floor in the field, there was no flower. A researcher suggested going back to the hive and taking another look at the two dances. When they did, Ms. Jones asked the class again, "But why isn't it, why isn't there [a red flower] right here?" as she pointed to the spot on the floor where the bee ended its dance. Jesse finally had the insight that the bees start their dances at arbitrary points within the hive. Zed did not respond to Jesse's idea (which, from Ms. Jones's point of view, was on the right track of the lesson), but instead offered a lengthy new narrative about bees laying down invisible tracks for other bees to follow. Ms. Jones let Zed have the floor and acknowledged his idea, but she also put the needs of the ensemble first when she went back to Jesse and asked, "What could those arrows represent?" referencing the red arrows built into the software that indicate the direction the bee dances. Jesse tentatively suggested, "You start there?" Ms. Jones repeated his idea. Zed then abandoned his original idea and began to work with Jesse's, adding an important insight that focused their attention on the direction and relative angle of the dance in comparison to the sun.

Excerpt 5
*Episode 2, Scene 2*

| Turn | Speaker | Talk | Action |
|---|---|---|---|
| 1 | Ms. Jones | But why isn't it, why isn't there one right here? | *Walks in mixed reality space to the spot where it looks like the red flower "should" be* |

**Instructional improv as a framework for teaching and learning** (Continued)

| 2 | Zed, David, and other students | [Talk over each other about target science content] | |
|---|---|---|---|
| 3 | Ms. Jones | Wait there's [laughs] there's a lot going on | |
| 4 | Jesse | Oh, it's because the, they, they can start wherever they want, they start from the hive, though | *Calls from the discussion space* |
| 5 | Zed | But look it. Um, the reason the blue one's not in the hive and making a track is because it has no more nectar so it's going to more flowers to find nectar and these bees have enough nectar so they are going into the hive and making a track, which is making, they're making a track with nectar so the other bees can follow the track | *Walks around mixed reality space as he explains, gestures for the track by waggling his finger back and forth* |
| 6 | Ms. Jones | Awesome | |
| 7 | Zed | And there's little red arrows that point | |
| 8 | Ms. Jones | Okay, so, Jesse, what could these arrows represent? | *Pointing to red arrows on the screen* |
| 9 | Jesse | You start there? | |
| 10 | Ms. Jones | That's where you start | |
| 11 | Zed | And then you go up, and if you start there, then you go the other way | |

We argue that the instructional improv model reveals how Ms. Jones shaped class discourse as she *agreed* with Zed's contribution in turn 6 by acknowledging it, but shifted her focus to the larger ensemble of students (including Zed) so they could work together to construct a coherent scene and *tell a story* together. And given time constraints of the lesson and the social pressure to make one's interactional turn connected to the next (Erickson, 1996; Schegloff, 2007; Schegloff & Sacks, 1973), the students worked together. Zed's attempt to connect his line of reasoning to Jesse's in turn 7 was enough of an opening for Ms. Jones to nudge the scene back in the direction of the lesson. When she asked, "What could these arrows represent?" she opened up space for Jesse to direct the scene and establish that the little red arrows were an important marker of the dance origin. Ms. Jones then added a critical piece of information related to the science content she hoped they would hang onto––that bees always start from the hive when leaving to forage for nectar but inside the hive the bees start from an arbitrary point marked by the little red arrows.

While Ms. Jones could have told students how the dance worked or what the arrow meant, the instructional improv model helps us identify the collection of improvised moves in the class discourse––including a combination of agreement, yes, and …, seeing mistakes as opportunities, making statements, prioritizing the needs of the ensemble, and telling a story––that kept the scene moving in the right direction while offering students agency and conceptual ownership of the content and discoveries.

### Ms. Jones's perspective on using improvisation to balance goals and student agency

We see instructional improv as a tool for researchers to understand how a teacher shapes discourse in student-driven learning. After developing our model, we interviewed Ms. Jones to gain insight on how she thought about her own teaching practice

and if and how instructional improv fit with her perspective. Though we acknowledge that our relationship with Ms. Jones may have led to confirmation bias of our conjectures linking improv with her instructional practice, we attempted to reduce this possibility by making it clear prior to the interview that we were open to disagreement and/or any additional interpretations she had to offer. On the other hand, it is also possible that our close working relationship allowed Ms. Jones to be more honest than she would have been otherwise. Nevertheless, however our relationship shaped the member check of our findings, we present three themes that emerged from the interview: (1) Ms. Jones positioned student-driven learning as shifting power and agency to students; (2) Ms. Jones kept the instructional story in the back of her mind as she balanced the tension between learning and agency; and (3) Ms. Jones saw instructional improv as a useful frame for understanding a teacher's decision making process in inquiry-based, student-driven learning environments.

**Shifting power and agency** Ms. Jones highlighted the importance of what the STEP environment did for her students, that it made "visible their ideas in a different way and allows them to test theories and get feedback for those different theories" (Ms. Jones, personal communication, March 5, 2018). For Ms. Jones, the instructional moves that worked best to support student-driven learning within STEP built from students' theories and shifted agency, power, and authority in her classroom. She explained:

> The teacher has such a role of like power and authority that whatever I say automatically goes … if I say you're right, you're right. If I say you're wrong, you're wrong. As opposed to, they're able to see the technology is showing me this, so I can decide that I'm right because of what I'm seeing.

There were several instances in which Ms. Jones shifted power and authority to her students in ways that made visible student ideas to be shared and tested. For example, in Episode 1, Scene 1 Ms. Jones shifted power and authority as she engaged the rule of *no mistakes, only opportunities* to encourage students to openly explore with the technology. They then discovered on their own that by hovering over flowers, their avatar bees collected nectar and pollinated. As a second example, when Ms. Jones made a *yes, and …* move in response to Zed's repeated exclamations of "I get this! I get this!" in Episode 1, Scene 2, she gave him the floor to explain his understanding that bees collected nectar at flowers and then filled the hive up with nectar. Importantly, Zed (and not Ms. Jones) publicly explained how nectar collection worked to the class, representing a shift in how power and authority are often distributed in traditional classrooms.

**Balance between learning and agency** Though the mixed reality supported Ms. Jones in relinquishing power and authority, she explained that this was the nature of how she taught inquiry with or without technology. She described there was always a notable tension between balancing content learning and student agency in her inquiry practice. She noted:

> I think that there is that tension. It depends on the group because...when there is more of like a collective whole or ...like when Emmie was really excited about colony collapse like we can go with that and we can study that because there's ways

we can work in the big ideas of interdependence and what plants and animals need to survive which is the standards and we can look at that through colony collapse...but it depends on if there's ways that I can tie in. So I kind of have the standards and learning objectives in the back of my head and then...we can kind of have a conversation and say where do you wanna go? And they have good ideas and you can do that...."

Ms. Jones discussed how she keeps student learning and what we call the instructional improv move of *telling a story* in mind by keeping standards and objectives "in the back of [her] head" as she follows student interests. This was made visible in the STEP environment because even as Ms. Jones followed happenings that took the class away from the target science content (e.g., Zed playing a dead bee) she kept pushing the story ahead to explain the complex system of bee communication.

**Instructional improv as a frame for teacher decision-making** We discussed our instructional improv model with Ms. Jones in our interview. Ms. Jones found promise in the idea of using improv as a way to help teachers learn how to guide conversations, explaining that it is hard to implement student-centered learning. She thought that our improv frame shifted agency and power to students during inquiry, and "that's hard to teach to new teachers like how do you guide the conversation in a certain way and play off of what the kids are saying so it feels like the kids are coming to the conclusions themselves." She explained that you "[shape] the conversation or the activity or the knowledge building [using student-generated ideas]." This shaping was evident in Episode 2, Scene 2 when Ms. Jones combined Jesse and Zed's contributions to connect the arrow symbol with the meaning of where bees start their waggle dances in the hive.

To Ms. Jones, our model helped explain the spirit of learning, inquiry, and discourse in the STEP environment. She explained:

[Improv] does help break down all of the things that I'm doing or that other teachers are doing subconsciously. That when you watch teachers that are really good at guiding the conversation...there's a lot they are doing subconsciously and that helps bring it out.

Ms. Jones's reflection aligned instructional improv with how teachers made decisions to support learning in a student-driven environment. While our model is not sufficiently translated for teachers and in its present form, Ms. Jones illuminated the possibility for instructional improv to be useful for practitioners striving to shift power and agency to students during class discussions.

## Discussion

Overall, we see instructional improv as a useful model for researchers because it helps to explain how teachers support science discourse in student-driven learning environments as they (a) shift power and agency to students; (b) balance learning and agency within lessons; and (c) make decisions during moments of instruction. The collective force of a teacher's overlapping improvisational moves to structure classroom discourse

strike a productive balance between these aims so that students are engaged in the doing of science (Jaber & Hammer, 2016a; Jaber & Hammer, 2016b) while at the same time they show evidence of learning the target science content intended in the curriculum. What instructional improv does is provide a framework for describing what teachers like Ms. Jones do to help get students to learn and enjoy learning science in a student-driven learning environment at the interactional level of analysis. In particular, the instructional improv model helps to highlight how teachers might strike a balance between planned structures, and adapting to student agency.

Our case study suggests that the instructional improv model can help us understand the interactional moves that teachers use to position student mistakes and misunderstandings as productive moments. This kind of instructional improv encourages students to exert their agency and learn science concepts even if some scientifically inaccurate individual student responses are made a legitimate part of the class conversation. For example, even when Ms. Jones validated some of Zed's tangential contributions, the class (both as a whole in class discussion and individual students within interview assessments) ultimately ended with understandings aligned with learning objectives written in the intended curriculum. (And Zed did, too.) Furthermore, we saw that Ms. Jones's improv moves supported student agency and collective ownership of knowledge as students saw themselves as valuable contributors to the discourse space. As evidenced in the data from Jade's outburst of "You just ate the nectar!" (Excerpt 1), to Zed's emotionally-charged explanation of his shocking death (Excerpt 4), and as multiple students shouted over each other about the target science (Excerpt 5), students were highly engaged with the content. Through it all, instructional improv explained Ms. Jones's adaptability and playful approach in classroom moments. Notably, her own laughter was part of the science, which may have helped her build relationships with students and encouraged their engagement (Roth et al., 2011).

Instructional improv helps explain how Ms. Jones balanced learning and agency within cycles of reflective discussions about student ideas. When individual ideas were taken up by the teacher, whether they aligned with the focus of the day's lesson or not, students became more deeply engaged with the inquiry because they were free to pursue a wider range of possibilities. Take for example in Excerpt 2 how students simultaneously reacted to what was happening in the mixed reality space as they shared their reflections about what the different animations might mean. Their ideas built on one another to construct a cohesive story relating nectar and pollen. Ms. Jones agreed with student ideas, including Jesse's that "little dots … means you're pollinating" and Zed's that "a heart comes up and that means you fill the … hive with nectar," yet asked the question, "the honey?" to inspire reflection and deeper comprehension of the difference between pollen and nectar.

Adding to recent reform recommendations for structuring science discussions (Michaels & O'Connor, 2012; Michaels et al., 2008; NGSS Lead States, 2013; Reiser, 2013), instructional improv provides a model for understanding how teachers can create the conditions necessary for productive science talk in student-driven environments. Instructional improv shows how teachers like Ms. Jones make the class conversation feel like a co-constructed story in which everyone plays a part in the narrative. Instructional improv places an emphasis on teachers working with students to co-construct a coherent story with their students as a way of supporting their scientific

inquiry. At first glance, this appears similar to Reiser's (2013) suggestion that teachers can learn to help facilitate scientific argumentation by focusing on how they work with students to produce a coherent storyline rather than focusing more narrowly on implementing specific techniques. Where the two approaches appear to diverge is that Reiser's storylines place the emphasis on the structure of the science story, whereas improvisation places the emphasis on how the teacher works with student ideas to produce an emergent yet coherent story. We see these two approaches as potentially complementary, with Reiser's framework providing some guidance for how to craft classroom storylines that support the practice of argumentation, and instructional improv providing guidance on how to organize the group's ideas into a storyline (argumentative or otherwise) in ways that still help students develop their agency and connect to the classroom activity. This last piece we see as potentially important for promoting student engagement and connection to science.

## Recommendations

In considering implications and future recommendations for analyzing student-driven learning environments, we realize the limitations of our example in this paper, that it was taken from a highly technical and instrumented environment that lends itself to a playful approach to teaching and learning. Nonetheless, we do not think instructional improv is limited to understanding teaching and learning in mixed reality environments. Just the opposite, because this tension between plans and responsiveness is ubiquitous for teachers (as Ms. Jones confirmed in her interview), we think that this instructional improv model can be a useful framework for researchers to analyze many different kinds of science lessons (and potentially lessons in other subject areas). While the mixed reality visualization made taking on roles and constructing a narrative around those roles prominent, there is no reason to suspect that there are not ways to engage students in scientific role play without technological support (e.g., Peleg & Baram-Tsabari, 2011). The focus here is on how to use ideas from theatrical improvisation to understand how teachers orchestrate discourse to encourage engagement and a high degree of student agency within learning.

   Building from Ms. Jones's interview reflections, future work for teacher education may include translating the model of instructional improv into a practical framework that teachers can readily use to guide interactions in science classrooms. Developing a professional development model for instructional improv may also be a necessary part of its translation. We believe that conversations around instructional improv will be valuable for how they can help teachers and researchers alike focus on how teachers can balance classroom plans with student agency in an effort to invite participation in science activities.

**Author details**
[1]University of California, Irvine, Irvine, USA. [2]University of California, Los Angeles, Los Angeles, USA. [3]Vanderbilt University, Nashville, USA. [4]Indiana University, Bloomington, USA.

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