A Modified Recipe for Interactive Classroom Demonstrations

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Interactive classroom demonstrations (ICDs) are used extensively in physics, and prior studies indicate that, when conducted under certain conditions, lead to appreciable increases in student gains and retention[1-12]. The literature suggests that the ICD recipe for maximizing student gain is to i) introduce the physical theory that will be demonstrated, ii) describe the demonstration and prompt students to record a prediction for what will happen, iii) conduct the demonstration, and iv) return to the prediction for students to reconcile their hypotheses[1,4,6,8,9,10,12,13]. Here, I propose two interrelated updates to leverage the particular strengths of Generation Z students currently enrolled in introductory physics courses[14-17] as well as to address potential pitfalls in the canonical ICD recipe[8-10,13,18-22]: the inclusion of simple, yet flashy demonstrations, and the integration of social media to disseminate and further engage with the results.

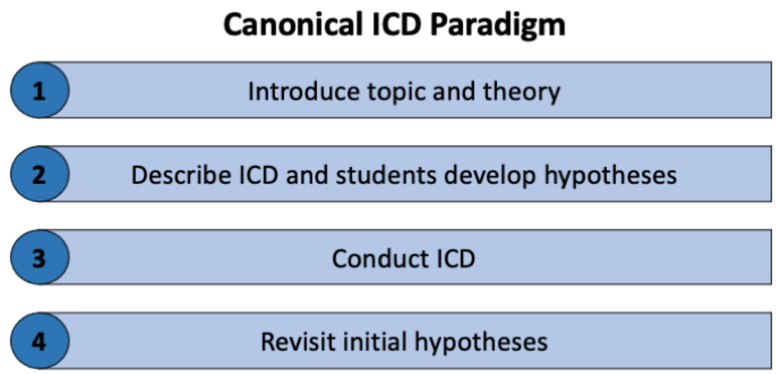

Figure 1: Canonical paradigm for ICDs based on the physics education literature.

Introductory college physics courses bring together students with a variety of skills, experiences, and preferred learning strategies[23]. For many students majoring in the physical sciences and engineering, it's their first college-level science class and they are adjusting to the rigors and pace of a college physics course. These students typically join advanced life science students who traditionally have more experience in college-level science courses, but more apprehension regarding the mathematical formalism presented in introductory college physics. ICDs have been shown to be useful in teaching students from all backgrounds in introductory physics courses since they provide students the opportunity to build intuition about a topic before attempting rigorous problems[1,5,6]. In addition to helping students to visualize new topics and build intuition, there are two additional, important purposes for conducting ICDs. First, ICDs help to build community among the students through the discussion of hypotheses (described in the next paragraph)[10,16,24,25]. Second, it has been suggested that the use of ICDs may narrow the gender gap in introductory courses, which may increase the retention of women and groups historically under-represented in physics[26]. ICDs therefore serve several purposes and remain a fixture in introductory college physics courses.

The canonical paradigm for ICDs has been developed over the past several decades and has four essential elements (see figure 1)[5,6,8,10,12]. First, the instructor introduces the topic and the theory, typically using the full mathematical formalism, which the subsequent ICD will help to clarify. Second, the ICD is described by the instructor and put into the framework of cause and effect. In other words, based on the theory that the students just learned, they hypothesize what will happen if the instructor does a specific action. This step first occurs individually and, after students have individual hypotheses, students share their hypotheses in groups (using active learning techniques, such as think-pair-share). This step reinforces the educational gain, as students are able to discuss it together using their collective backgrounds, which may be more advantageous than the instructor's explanation[9,10,12,13]. Third, the demonstration is conducted, with student participation as necessary. Fourth, and equally as important as the second step, students revisit their hypotheses and resolve any misconceptions[9,10,12,13]. Again, working in groups is beneficial as students may use their shared, collective experiences to reconcile their understanding in a way that the instructor is unable to do. Studies have shown that if this step is skipped, students will further solidify their misconceptions[12,21,22].

Over the past several years, I have implemented the traditional ICD paradigm into my year-long General Physics course sequence and have made several changes. The revised paradigm that I present is based on observations from the class, particularly based on the strengths of the current demographic of students (Generation Z). One modification that I have made to the canonical ICD paradigm is in the selection process for individual demonstrations. With at least one ICD per class and three class meetings per week, I aim to have at least one of what I refer to as simple, yet flashy demonstrations per week. While canonical, more pedestrian demonstrations are still used and build linearly upon each other as has been suggested in the literature[1,2,6,9,10,11,13] these special simple and flashy demonstrations serve two pedagogical purposes: i) to clearly illustrate the underlying physics (using simple demonstrations has been shown in the literature to be essential for educational gains[13]) and ii) to engage the students[1,5,9,24]. With the prevalence of social media, students have become less invested in traditional and pedestrian demonstrations – they are instead actively searching for moments that are unique and shareable[27]. By having flashy demonstrations, students may become drawn in and invested in the demonstration[14-16]. Importantly, the use of flashy demonstrations is not to provide entertainment for the students; such an approach has been shown to provide limited gains in student learning[9,13]. The guiding principle in selecting demonstrations is providing a simple, large-scale demonstration without any caveats, that elegantly portrays the physics being taught. The flashy aspect is a vehicle by which the instructor simply shows the underlying physical principles. Consistent with the literature, the ICDs that I conduct with this revised paradigm are a mix of qualitative (students provide their hypothesis) and quantitative (students conduct a calculation to accompany their hypothesis)[7].

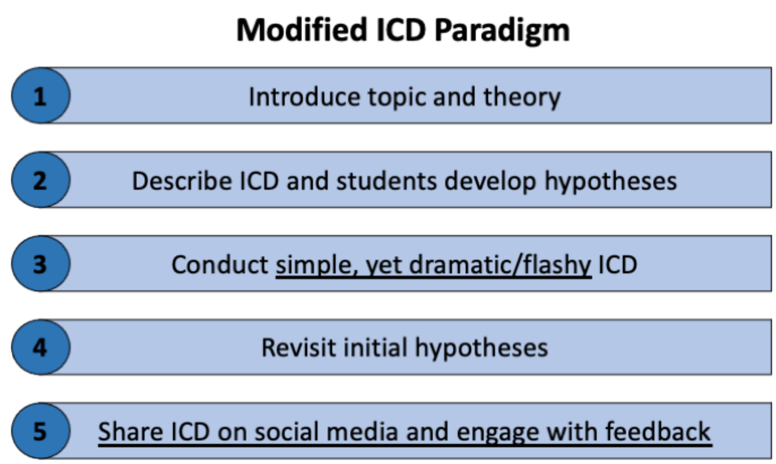

Figure 2: Proposed ICD paradigm. Note that the primary modifications are in the third step (choosing which ICD to conduct) and the addition of the fifth step, which is the dissemination of results via social media.

Relatedly, the second modification that I have made to the canonical ICD framework is the inclusion of students sharing demonstration images, videos and, most importantly, results via social media. While the dissemination of results may seem second-nature to established scientists, this is a novel idea to students[8,20]. Encouraging students to share footage of ICDs on social media serves several purposes. The first purpose is to provide students with yet another opportunity to return to and examine their original hypotheses. Students are very conscious of what they post to their social media, and the posting of these demos encourages students to reaffirm the physics they observed. The second purpose of this sharing is to encourage students to spend more time engaging with the material. Regardless of the social media platform, posts are seldom left without follow-up discussion, and such discussion encourages students to spend more time outside of class engaging with the material, continually reinforcing the theory underlying the ICD. This mode of commenting on their social media post provides an opportunity to qualitatively describe the physics which, when paired with the numeric problem sets, guides them in achieving a holistic study of the course material (see figure 2 for the revised ICD paradigm). Using the parlance of educational psychology, this second modification to the canonical ICD framework is an exercise in elaborative learning (describing the demonstration as well as engaging in comments and questions about the demonstration on social media) and the testing effect (revisiting and engaging with the material over an extended period of time by commenting on and answering questions about the demo on social media), both of which have been shown in the literature to increase student gains[28-34]. Although the use of social media in the physics classroom has been limited, preliminary observations and studies across high school and college classes of varying sizes suggest social media alone may positively impact student engagement[35-39] and, potentially, grades[38].

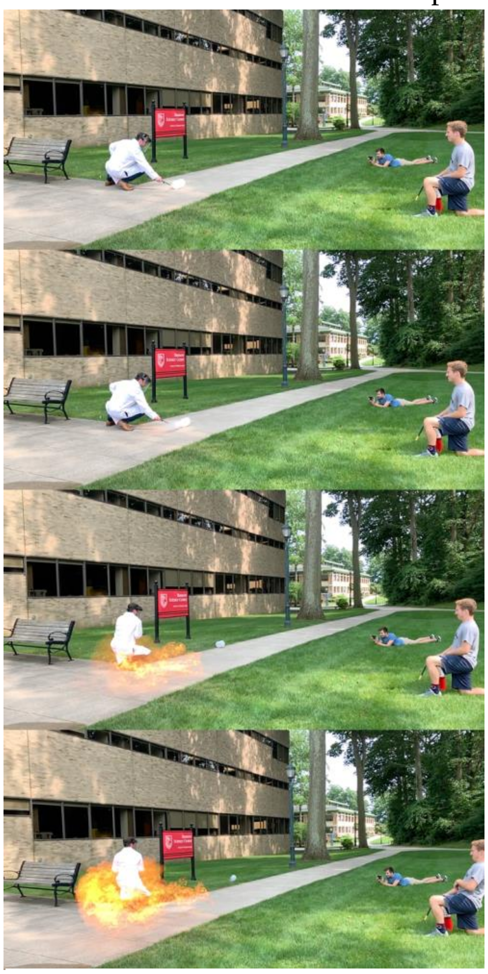

Figure 3: Snapshots of rocket ICD for conservation of momentum. In this ICD, students make a qualitative hypothesis as well as conduct the corresponding calculation.

To illustrate this modified ICD paradigm, I consider an ICD used for conservation of momentum. While students typically associate conservation of momentum with collisions, I have observed that they are less likely to apply this concept to explosions, for which momentum is still conserved. In order to address this misunderstanding, I have used a modified version of the rocket demonstration that has been used in many introductory physics classrooms. First, ethanol is vaporized in a gallon-sized plastic bottle. After a few minutes, the cap is removed and the bottle is placed on its side on the ground (conducted outside). A flame is then held at the mouth of the bottle, creating the required catalyst to force the air out of the opening and propel the bottle in the opposite direction (see figure 3).

Before conducting this demonstration, I explain to students that a bottle (with given mass and volume) is filled with air (with given density). Then, an explosion causes the air to quickly rush out of the bottle. I first ask students to describe qualitatively what will happen (their hypothesis) based on their own understanding of the material and then compare their hypotheses with students sitting at their classroom table. Once they have recorded their hypotheses, I conduct the demonstration outside with the students. Before beginning, I also ask students to record the demonstration using a slow-motion photography app on their phone. After the demonstration has been conducted, we revisit their hypotheses, providing sufficient time for them to speak with the same classmates they consulted earlier and reconcile their expectations/hypotheses with their observation of the demonstration. As an additional step for this ICD, students use the slow motion video from their phones to track the movement of the bottle and air/flames to calculate the respective velocities and show that momentum was conserved. Finally, students share their images/videos via social media with a description of what they observed and are encouraged to engage in further explanation as these social media posts receive comments. Although this aspect is ungraded, students are excited to complete this step to share what they've learned through the ICD with their peers.

While the rocket demonstration has been used in many physics classes, its use here highlights the key elements of the modified ICD framework. First, this demo is presented in a simple manner. Traditionally, such a demonstration would be used to illustrate the rocket equations, which have significantly more complicated math. For the purposes of General Physics, this complexity is not necessary and detracts from the underlying theory of conservation of momentum. Thus, choosing a demonstration that can be used to show the physics in a simple and straightforward manner is important as is the fact that this demonstration fits well within the linear sequence of more traditional momentum ICDs (i.e. such as gliders colliding on a track). Furthermore, this demonstration satisfies the modified ICD condition of being dramatic or flashy. The experience of seeing the fire ball and watching the bottle skid in the opposite direction of the flames is impactful, and elicits buy-in from the students to understand the topic and revisit their hypotheses. With the prominence of social media and students searching for sharable, "Instagramable" moments, the regular incorporation of dramatic and flashy ICDs keeps students invested and excited to generate and revise their hypotheses for the demonstration (based on anonymous student evaluations). Similarly, this flashy yet simple ICD lends itself well to social media. Students have reported that for this demonstration, among others, they spend time outside of class engaging with the material via social media by responding to their friends' comments and questions.

As illustrated by this anecdote, many ICDs utilized in this revised paradigm require an adaptive environment due to their scope. While not necessary, access to an outdoor area or a large classroom with movable furniture is beneficial to accommodate many of these dramatic demonstrations. Although not required, many of the ICDs conducted using this revised paradigm benefit from a high-speed camera to track the evolution of the demonstration in slow-motion.

While this paradigm has been refined over the past three years in the year-long General Physics course sequence at a primarily-undergraduate institution, the feedback used to gauge the success of this paradigm is qualitative. Specifically, student feedback in the form of individual conversations, end-of-semester confidential student evaluations, and assessments of my teaching by faculty colleagues have all suggested this paradigm i) increases student engagement, ii) increases students' perceived investment in learning the course material, and iii) increases students' perceived gains in the course. These forms of assessment (student-evaluations, in particular) have been shown to have some bias[40], and a follow-up study quantitatively assessing these three perceived increases due to the pedagogy is planned, both in the context of introductory physics as well as another introductory science course. In the interim, the feedback received by students and other educators suggests that this revised ICD paradigm may be worth pursuing in introductory physics courses, particularly as physics faculty look to increase student participation in the hybrid landscape and champion equity in the classroom.

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