Impetus-Force-Like Drawings May Be Less Common Than You Think

Cite as: Phys. Teach. **60**, 254 (2022); https://doi.org/10.1119/5.0027858
Published Online: 25 March 2022

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Impetus-Force-Like Drawings May Be Less Common Than You Think

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Perhaps the most commonly cited student idea about forces in the literature is the notion of an impetus force,[1-25] defined as the "belief that there is a force inside a moving object that keeps it going and causes it to have some speed," that can then "fade away as the object moves along."[15] According to the literature, even after physics instruction students use impetus force reasoning to argue that forces are necessary to sustain motion[5-9,22] or that motion implies force.[7,9-12,14,22] For example, many students drew an upward arrow to indicate a force on a coin that was moving upward after being tossed. The coin was halfway between the point of its release and its turnaround point. Interviews with students in the course indicate that the arrow was meant to indicate "the 'force of the throw,' the 'upward original force,'" and so on. Clement interprets these results to mean that students "believe that continuing motion implies the presence of a continuing force in the same direction, as a necessary cause of the motion."

A number of other studies have been designed to elicit impetus-force-like ideas (e.g., Refs. 6, 21, and 24). The impression these articles give is that impetus-force-like ideas are *persistent, common*, and, in Clement's words, *concerning*. This is communicated both by the language that the articles use and by the percentages they report. For example, authors say that the impetus force idea is "particularly strong"[3]; "especially common,"[3] used by "many students"[6,21]; "shows up in a wider diversity of problem situations than one would expect,"[3] including "a wide variety of simple situations"[21]; "appears to still be present in many students after they have completed a course in mechanics" (which is then named as a "rather disturbing result"[3]); and "appears to be a major stumbling block in the physics curriculum."[3] (This language is consistent with prevailing notions of misconceptions in the '80s and '90s, as stable conceptions resistant to change and that act as barriers to student learning, e.g., Refs. 4, 26, and 27.) The commonality of these ideas, as inferred from students' drawings, ranges from 33%[21] to 75%,[3] again suggesting that students use these ideas frequently.

The prevalence and persistence of the impetus force idea has prompted large-scale curriculum development and instructional planning to address it. In this paper, we report on a set of preliminary results that challenges the universality of the assumption that *many* students have impetus-like ideas that *persist* through instruction. In our study, we asked questions from a number of the studies we cite above, and we used similar methods as described in those papers to code student drawings for impetus-like ideas. We found that the frequency of impetus-like drawings (a) was consistently less than reported in previous studies, including those that report post-instructional results, and (b) varied across samples.

This matters because what instructors think about student thinking shapes their instructional decision-making.[28,29] For example, an instructor who assumes that the impetus force idea is common and persistent may plan instruction to address it, be likely to hear this idea in what students say and do, and pay careful attention to whether or not students continue to use this idea in homework and on exams. An instructor who believes that this idea is uncommon and/or not particularly persistent may foreground other considerations. In other words, the expected ubiquity and persistence of the impetus force idea becomes another lens—beyond an awareness of the idea itself —through which instructors plan and interpret. This paper has implications for that lens.

Methods

A detailed methods section can be found in Appendix A.[30] Here we offer an abbreviated overview of the questions we used, our sample, and how we analyzed student responses.

This study grew out of a larger effort to identify university student resources for understanding physics—ideas that can be framed as "beginnings" of sophisticated scientific understandings.[31-35] As part of that broader effort, we gave students a number of conceptual questions that had been used in previous studies, to see whether a resources-oriented analysis would yield a different set of categories of student thinking. Our analysis for this paper emerged from an initial noticing that the frequency of impetus-like drawings seemed to be much lower among students in our samples than the frequencies reported in the original studies. We pursued this noticing by analyzing student responses to three questions: the *modified coin toss* question, the *curved tubes* question, and the *pendulum* question, all featured in Fig. 1.

The *modified coin toss* question, *curved tubes* question, and *pendulum* question are (slightly) modified versions of questions used in previous studies documenting student use of impetus-like drawings. The *modified coin toss* question was adapted from a question used in a study done by Clement (mentioned in the introduction)[3] who found that students often drew upward-pointing arrows on the tossed object at point B, indicating an impetus-like "toss" or "hand" force sustaining the object's motion. The *curved tubes* question is a slightly modified version of a question used by McCloskey, Caramazza, and Green.[21] These authors found that students often drew curved paths for balls exiting curved tubes; they interpreted these curved paths as impetus-like, since they indicate that the ball "will continue in curved motion even when no external forces act on it." The *pendulum* question was adapted from Sadanand and Kess,[6] who observed that stu-

 DOI: 10.1119/5.0027858

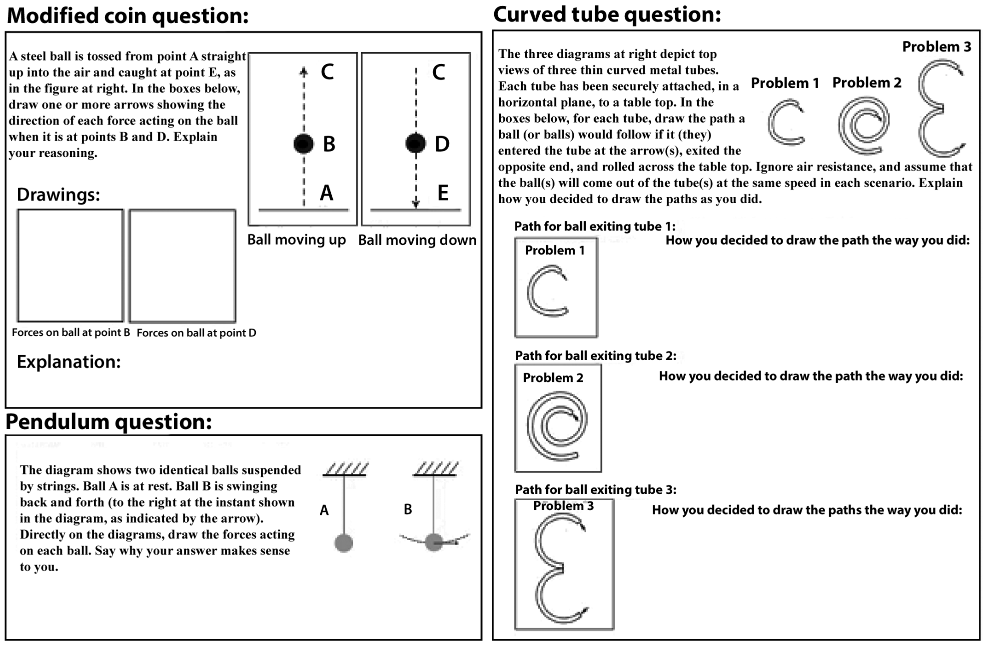

Fig. 1. Questions used in our study. Images of curved tubes from M. McCloskey, A. Caramazza, and B. Green, "Curvilinear Motion in the Absence of External Forces: Naïve Beliefs about the Motion of Objects," *Science* 210 (4), 1139-1141 (1980). Reprinted with permission from AAAS.

dents often drew a horizontal arrow in the direction of motion for ball B, indicating that "many students invoke forces in the direction of motion even when there seems to be nothing that can generate that force."

We analyzed student responses to these three questions, from students enrolled in introductory physics courses at six different U.S. universities, Universities A through F. Six hundred forty-four students answered the *modified coin toss* question, 214 the *curved tubes* question, and 429 the *pendulum* question after relevant instruction about forces and motion. As we describe in detail in Appendix A,[30] our study likely oversamples from Asian and wealthy populations and undersamples from Latinx and Black populations, limiting the generalizability of our results. However, our primary aim has not been to produce a generalizable result; it is to call into question the impression that impetus-like responses are *universally common and persistent.*

Because our goal was to compare the frequencies of impetus-like responses in the original studies to those in our sample, we sought to use the same methods for coding student diagrams as the original authors to the extent possible. That means that we counted as impetus-like: all upward arrows at point B in the *modified coin toss* question; all curved trajectories for the ball as it exited the tubes in the *curved trajectories* question; and all horizontal arrows pointing in the direction of motion in the *pendulum* question. More details about how our methods compare to those of the original authors can be found in Appendix A.[30]

Two independent coders—authors ADR and LMG —coded student responses. Because we are seeking to *challenge* the literature's read on the prevalence and persistence of impetus-like drawings, we took the approach that offers the most generous interpretation of a drawing as impetus-like. In particular, a drawing was included in the percentages reported in the next section if *either* coder deemed it impetus-like. Even with this generous approach, we mostly agreed on which drawings were impetus-like; our percentage agreement was 98.5%.

Results and discussion

Figure 2 compares the percentages of impetus-like drawings reported by the three studies discussed above (blue bars) to the percentages of impetus-like drawings among the students in our samples (yellow bars for individual samples, brown bars for overall). (For the *curved tubes* question, the darker bars are for Problem 1 and the lighter bars for Problem 2.) **What Fig. 2 illustrates to us is that the frequency of impetus-like drawings in our study both (a) is consistently less than reported in previous studies and (b) varies across samples.** This is true for all three questions in our study. This calls into question, for us, an interpretation of impetus-like thinking as universally *persistent and common*. For some samples, this kind of reasoning, as evidenced in drawings, is in fact quite *un*common.

What we cannot tell yet is *why* our results are so different than those from previous studies. The results Clement reports (reproduced in Fig. 2) are post-instructional; those that Caramazza et al. report are largely post-instructional (32 of 47 of their research subjects had previously taken a high school or college physics course); and Sadanand and Kess do not tell us when they gave their questions, only that the students in their study were "college-bound seniors…enrolled in an elective course in noncalculus-based physics." It's not enough (and in fact is not accurate) to say that our results are different because of *when* the questions were asked. The variation between samples in our study supports this further, since all of these samples were given the questions post-instruction.

One possibility for why our results are different than the original studies is that the impetus force idea was never all that common and/or persistent, and the papers we have cited have been overgeneralized. This seems somewhat unlikely given the resonance of this research with so many instructors, but it's not outside the range of possible explanations. Though it would not have affected our comparison, since we modeled our methods after those used in earlier studies, we did explore the possibility that earlier researchers may have overattributed impetus-like thinking to students' drawings by looking at how students labeled their impetus-like arrows in our study. That is, might students who drew these arrows be thinking of them as velocity or acceleration vectors, or as frictional forces, such that the interpretation of all upward (or horizontal) arrows as impetus-like thinking is an over-attribution? Appendix B[30]

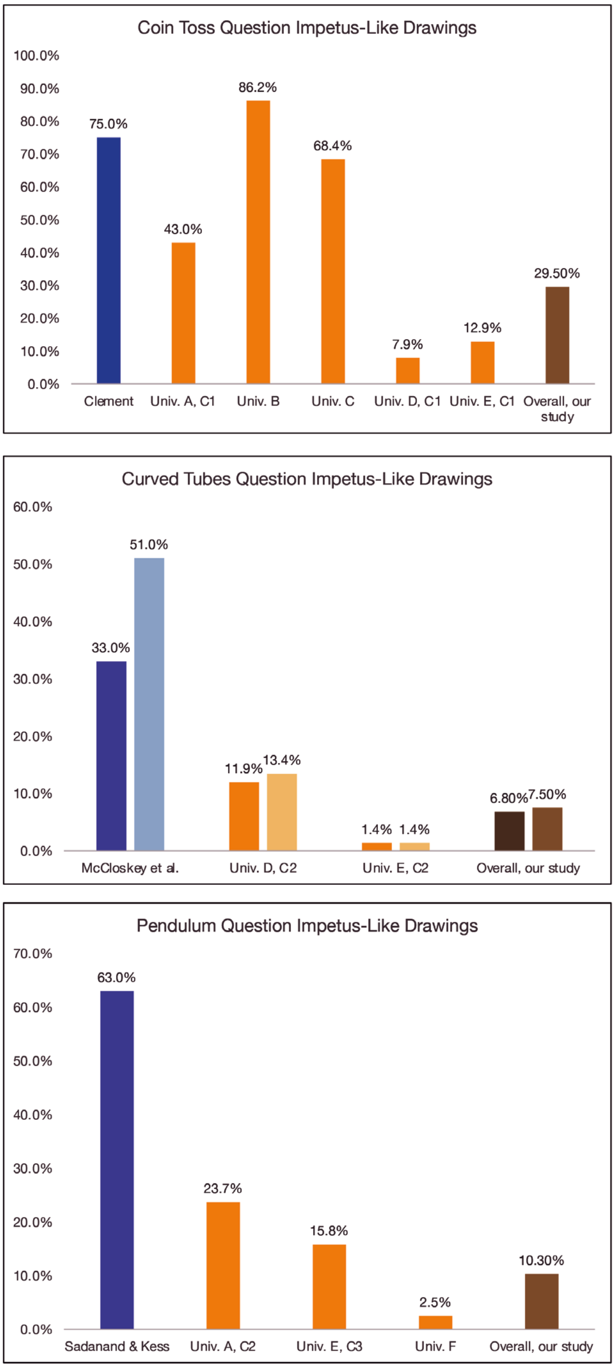

Fig. 2. Comparison of impetus-like drawings in original studies (blue) and our study (yellow, brown). "Univ." stands for "university," "C" for "course."

presents the results of this exploration. In short, most students (about 75%) who drew impetus-like arrows labeled them in ways consistent with impetus-like thinking, suggesting that in many cases these arrows do in fact indicate impetus-like reasoning.

A second possibility for why our results are different is that the impetus force idea is less common and/or persistent among introductory physics students in the present day. For example, perhaps we are seeing less frequent use of this idea post-instruction in our study because fewer students think this way in the first place, pre-instruction.

Yet another possibility is that the impetus force idea is effectively (though differentially) addressed by PER-informed instruction. Some of the original studies (e.g., Refs. 3, 21, and 24) hypothesize that physics instruction that "takes into account students' misconceptions about motion"[24] would address the prevalence of impetus-like responses. Since the early 1990s when these studies were published, the physics instructional community has certainly heeded this call, and all of the courses in our study were PER-informed.

One may wonder whether the modifications we made to the original questions contributed to the results in Fig. 2. We think not. It is very difficult for us to imagine the changes to the *coin toss* and *curved tubes* problems (described in Appendix A[30]), which we see as largely tweaks to format and clarity, effecting this degree of change. More substantive changes were made to the *pendulum* question—in particular, choosing a single direction of motion—but even when we include *all* horizontal arrows (in the direction of motion and opposite), the percentages come to 36.8% (University A, Course 2), 20.5% (University E, Course 3), 4.5% (University F), and 14.5% (overall). These are still consistently lower than Sadanand and Kess' reported percentage (63.0%) of impetus-like drawings, preserving our original claim. Perhaps even more importantly, if clarifying the questions in the ways we did *were* the source of the reduction in frequencies in Fig. 2—i.e., if that's all it took—it would support, rather than challenge, our overarching message that impetus-like thinking is not universally common and persistent.

Implications

Literature on common student ideas about forces can leave instructors with the impression that *many* students have impetus-force-like ideas that persist through physics instruction. Our results challenge the universality of this interpretation, showing that the frequency of impetus-like drawings is often less than in previous studies, including those that report post-instructional data. This finding nuances the interpretation of results that were produced decades ago and prompts a series of questions about why we got such different results in our study than researchers did then. Together with our results, answers to these questions may shift or sharpen the lens through which teachers plan for instruction and interpret student thinking.

Acknowledgments

The authors are grateful for feedback on portions of this draft from McKensie Mack and Raphael Mondesir, and for constructive conversations with members of our Advisory Board, including Andrew Elby, Fred Goldberg, Steve Kanim, and Sam McKagan. This work was supported in part by NSF Grant Numbers 1608510, 1608221, 1256082, 1914603, and 1914572.

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