Strong preference among graduate student teaching assistants for problems that are broken into parts for their students overshadows development of self-reliance in problem-solving

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Different physics problem types, i.e., the same physics scenario posed as a problem in different ways, can emphasize different learning goals for students and can be used in diverse situations to meet various instructional goals. We examined graduate teaching assistants' (TAs') views about broken-into-parts introductory physics problems within the context of a semester-long TA professional development course. The TAs were asked to list the pros and cons of the broken-into-parts problem type, rate this type of problem in terms of its instructional benefit and the level of challenge it might produce for their students, and describe when and how often they would use broken-into-parts problems in their own classes in different situations if they had complete control of teaching the class to meet different instructional goals. We find that TAs reported the broken-into-parts problem type to be the most instructionally beneficial out of all the problem types and would use a broken-into-parts problem type often and in a variety of ways (e.g., homework assignments, exams, and quizzes). Written explanations and interviews suggest that they preferred to use a broken-into-parts problem type more often than other problem types in various instructional contexts because of the guidance such problems offer. While providing guidance to students is an appropriate instructional approach, our findings from interviews suggest that many TAs may be motivated to assign broken-into-parts problems out of a desire to make the problem-solving process easy and/or less stressful for students, especially because they felt that introductory students may not be capable of breaking a problem into sub-problems on their own. The instructional benefits of gradually removing the scaffolding support to help students develop self-reliance in solving problems appeared to be overlooked by most TAs. This lack of awareness or reflection on the important role that removing scaffolding support gradually and providing adequate challenge can play in helping introductory students develop self-reliance and become independent, expert-like problem-solvers has implications for the professional development of TAs.

I. INTRODUCTION

The desired learning goals for students in many introductory physics courses often include learning physics concepts and developing expertise in problem-solving and reasoning skills [1–21]. The cognitive apprenticeship model can serve as a useful model to support these goals [22]. In this field-tested framework, learning takes place through a guided process in which students gradually develop self-reliance in solving problems on their own. To facilitate this process, the cognitive apprenticeship model includes three aspects: modeling by instructor or expert to demonstrate the criteria of good performance in problem-solving, coaching and scaffolding to provide immediate feedback as students engage in problem solving, and weaning the support to build autonomous expert-like problem-solving ability [22].

The role of different problem types in the development of expertise: Different problem types, i.e., different ways in which a physics problem is posed, can facilitate various aspects of the cognitive apprenticeship model, e.g., helping students develop expert-like problem-solving skills and learn physics [23–25]. For example, a problem that is broken into parts may be useful in modeling and coaching in expert-like problem-solving approaches in a particular context. Alternatively, a problem type that provides less support can help with the weaning aspect if used after modeling and coaching, and can provide opportunities for students to develop self-reliance in expert-like problem-solving. If students are mostly given problems which are broken into parts, they will not have many opportunities to practice decomposing problems into sub-problems on their own to gain problem-solving independence. Therefore, for the weaning aspect of developing problem solving skills, other problem types for the same physics scenario can be more beneficial [26, 27]. In other words, problems which provide built-in support and/or modeling, e.g., broken-into-parts problems, may be beneficial for the modeling and coaching aspects of student learning. However, after modeling, coaching and scaffolding, students also need opportunities to experience removal of the support so that they can be weaned into more independent execution of a systematic problem-solving approach. For the weaning aspect, when self-reliance is being developed, problems which provide less in the way of built-in support can be useful.

The role of TAs in promoting student learning: Many physics graduate teaching assistants (TAs) are potential future faculty. Moreover, now or in the future, they may be responsible for making decisions about the use of different problem types in different instructional situations depending upon their perceived instructional value and constraints [28–39]. Therefore, their views about the pros and cons of posing an introductory physics problem in different ways and in different instructional contexts can be useful in developing activities to improve their professional development and help them recognize the pedagogical value of posing the same problem in various ways. Here we summarize findings of an investigation focused on TAs' views about the pros and cons of broken-into-parts introductory physics problems.

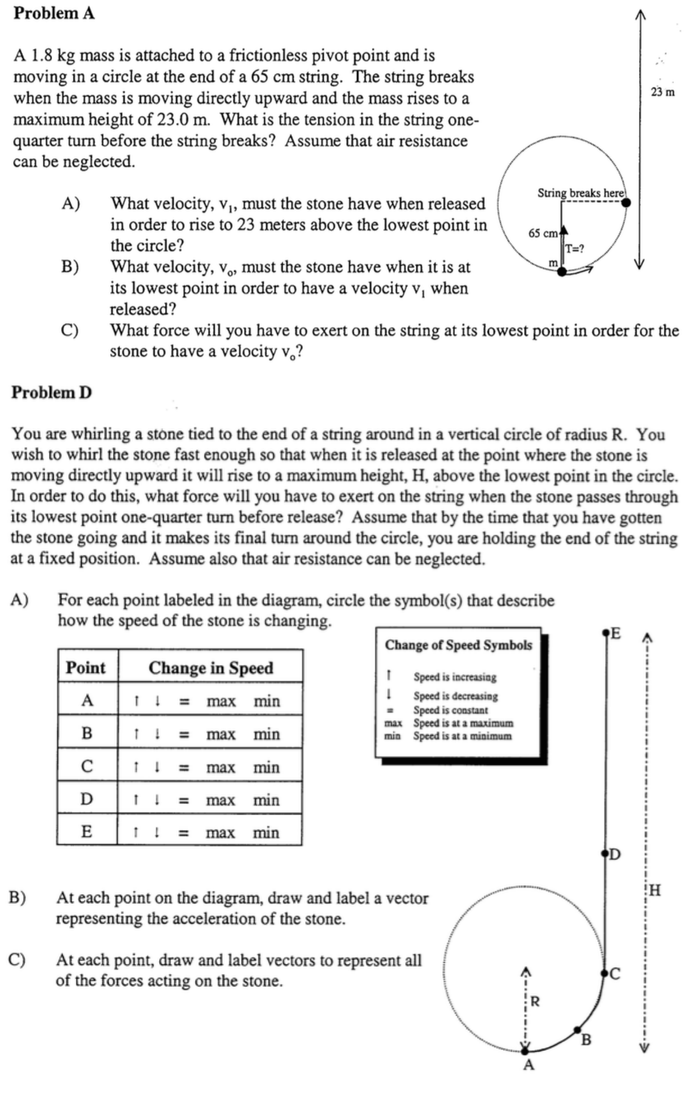
Physics faculty views about broken-into-parts problems: A prior study was conducted about physics instructors' views regarding different problems in which they were presented with the same problem types (including the broken-into-parts problems) given to the TAs in the current study [29]. It was found that the instructors generally valued different problem types intended to develop different aspects of expert-like problem-solving but their reported use of different problem types in their classes did not always reflect their beliefs regarding the instructional benefits of various problem types. Instructors had differing opinions about the merits of the broken-into-parts problem type. More than half of the instructors felt that it was important to lead students through a problem by breaking it up into sub-problems for the student, while slightly less than half of the instructors felt that students benefit from not providing such a guide. Nevertheless, the majority of instructors reported widely using broken-into-parts problems in homework, quizzes, and exams, even if they had reservations about such problems, stating that using such problems would help avoid stressful situations for students [29].

Focus of the research: In the study presented here, we focus specifically on the views of physics graduate student TAs about posing problems in two types of broken-into-parts format (problem posed with sub-problems provided). One of these problems has subproblems that do require explicit calculation, while the other does not (see 1). In particular, TAs in a professional development course were asked to reflect upon five problem types for the same introductory mechanics problem scenario in which two of the five problem types were broken-into-parts problems. Other problem types with which they were asked to compare broken-into-parts problem type in various instructional situations to meet different instructional goals included traditional textbook problem not broken-into-parts, context-rich and multiple-choice problem types. Although the TAs were asked to rank these problem types in general assuming well-validated problems of each problem type on various physics topics were available, for concreteness, they were presented with an example of each problem type in one context. Here, we describe an investigation focused on TAs views about the pros and cons of two introductory problems that are broken-into-parts and involve the same physics scenario.

II. METHODOLOGY

Participants: Participants consisted of 97 TAs from a large, selective, predominantely white, public, doctoral university with high research activity and a large physics program. Participants were selected during 4 different years. Participants were physics graduate students who had teaching responsibilities (e.g., introductory recitation or lab instruction) and were concurrently enrolled in a mandatory TA professional development course that met once per week for 2 hours for an entire semester. The TAs were expected to do approximately one hour of homework each week pertaining to the professional development course.

Data collection and artifacts: The data collection tools consisted of instructions and five example introductory



Problem A

A 1.8 kg mass is attached to a frictionless pivot point and is moving in a circle at the end of a 65 cm string. The string breaks when the mass is moving directly upward and the mass rises to a maximum height of 23.0 m. What is the tension in the string one-quarter turn before the string breaks? Assume that air resistance can be neglected.

A) What velocity, v_1, must the stone have when released in order to rise to 23 meters above the lowest point in the circle?

B) What velocity, v_o, must the stone have when it is at its lowest point in order to have a velocity v_1 when released?

C) What force will you have to exert on the string at its lowest point in order for the stone to have a velocity v_o?

Problem D

You are whirling a stone tied to the end of a string around in a vertical circle of radius R. You wish to whirl the stone fast enough so that when it is released at the point where the stone is moving directly upward it will rise to a maximum height, H, above the lowest point in the circle. In order to do this, what force will you have to exert on the string when the stone passes through its lowest point one-quarter turn before release? Assume that by the time that you have gotten the stone going and it makes its final turn around the circle, you are holding the end of the string at a fixed position. Assume also that air resistance can be neglected.

A) For each point labeled in the diagram, circle the symbol(s) that describe how the speed of the stone is changing.

Point	Change in Speed
A	↑ ↓ = max min
B	↑ ↓ = max min
C	↑ ↓ = max min
D	↑ ↓ = max min
E	↑ ↓ = max min

Change of Speed Symbols

↑ Speed is increasing
↓ Speed is decreasing
= Speed is constant
max Speed is at a maximum
min Speed is at a minimum

B) At each point on the diagram, draw and label a vector representing the acceleration of the stone.

C) At each point, draw and label vectors to represent all of the forces acting on the stone.

FIG. 1: The two broken-into-parts example problems given to the TAs to illustrate each broken-into-parts problem type.

physics problem types that had been developed previously to illustrate each problem type [29]. The example problem types were designed for an introductory physics problem scenario in mechanics and served as a guiding example for the activities. They included two different versions of a problem which was broken into sub-parts (a conceptual one and a quantitative one), a multiple-choice problem, a context-rich problem and a traditional textbook version of the problem.

Here we focus on the two broken-into-parts problem types. We note that it was made clear to the TAs several times that these were merely single concrete examples of broken-into-parts problem types for illustration purposes and that they should, in general, reflect upon the instructional benefits of well-designed problems.

The TAs were asked to answer questions about these problem types on a worksheet which included entries for pros, cons, and uses. In the most recent year's worksheet, TAs were also asked what they would change about the example problems. In addition, they were asked to rank the features of problem types on their instructional benefit, level of challenge (i.e., how difficult the TAs judged each problem type to be for students), how much they liked the problem types, and the likelihood that they would use the problem if they had complete control of the choice of the problem types to use. For example, a TA who ranked a problem 1 for "challenging" judged this problem to be the least challenging for students; a 5 for "challenging" indicates that the TA perceived it to be the most challenging among the five problem types. Furthermore, throughout all four years, TAs were asked to list pros and cons of the problem types. These pros and cons were useful for investigating why TAs ranked the problem types the way they did.

Data collection: TAs were given the example problem types and worksheets in the professional development course in the middle of the semester, when they had some teaching experience, in order to elicit their ideas about different problem types. They were asked to answer worksheet questions under the assumption that they had complete control over the introductory physics class, including control over problem types chosen for various purposes. The worksheet was completed as part of a homework assignment. We note that this semester-long course is the only such course physics TAs take at the institution and the course had already focused on some general issues related to physics teaching and learning, e.g., discussion of some physics education research findings relevant for introductory physics. Later, 12 participants who had taken the TA professional development course earlier volunteered to be interviewed in a one-on-one setting using a think-aloud protocol. These interviews took place at least one semester after the initial activity described here in the TA professional development course and were audio-recorded. TAs who participated in the interviews were asked questions both about the example problems given to illustrate a problem type and about the problem types in general. Thus, these interviews served to more deeply probe the TAs' reasoning behind their written responses and to explore how and to what extent the TAs might use the broken-into-parts problems if access to well-designed broken-into-parts problems was available.

Coding TA responses: Two of the researchers met weekly to identify appropriate coding categories for pros/cons; agreements on these were reached through discussion. The researchers focused on coding the data from the individual homework assigned in the middle of the semester regarding the TAs' views of the problem types. The inter-rater reliability was examined for the coding of the pros/cons in a subset of the data (encompassing one year of data), and the average Cohen's kappa [40] was calculated to be $\kappa = 0.982$. Table I includes the most common pros and cons for the broken-into-parts problem type.

III. RESULTS

Broken-into-parts problems ranked high for like, use, and instructional benefit, but low for challenge: As shown in Figure 2, the average rankings for the two broken-into-parts problem types are consistently high for "like," "use," and "instructional benefit," but low for "challenging." In fact, the broken-into-parts problem types received the highest rankings for "like," "use," and "instructional benefit," and the lowest

TABLE I: The most commonly listed pros/cons of the broken-into-parts problem type and the percentages of TAs who listed them.

Code	Definition	Examples	Percentage of TAs
(Pro) guide	walks students through step-by-step; helps students solve harder problems	"parts make the problem more guided"	80
(Con) help	provides too much support or makes the problem too easy	"student does not have to do too much thinking"	37

rankings for "challenging" out of the five problem types students were given. These rankings indicate that TAs appear to value these types of problem, although they find them not to be challenging for students.

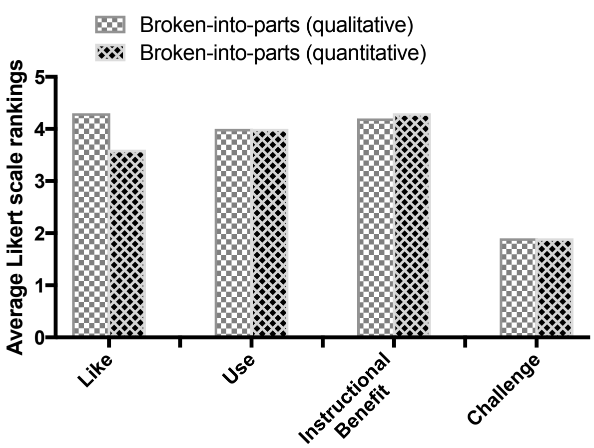


FIG. 2: Average rankings of the two broken-into-parts problem types

TAs reported potentially widely using the broken-into-parts problem type and preferred to use this problem type over other more challenging problem types: As seen in Figure 2, the TAs ranked the broken-into-parts problem types highly for "use." This ranking is the highest ranking of all problem types the TAs considered. Both of the broken-into-parts problems received an average ranking of 4 out of 5, indicating that TAs were far more likely to use this problem type compared to other problem types, the next highest ranking for which was only a 2.9 out of 5 in the category of "use."

Figure 3 summarizes the TAs' stated use of the broken-into-parts problem types, and shows that TAs reported that they would readily use this type of problem for homeworks, quizzes, and exams. It appears that the broken-into-parts problem type was one type of problem that TAs would readily use for many purposes. However, written responses and interview data hint at possibly excessive valuing and use of this type of problem, indicating a potential over-reliance on broken-into-parts problems. For example, in an interview, one TA stated: "I always prefer sub-questions" whether it is for homework, quizzes, or exams. Further discussion with the TA suggests that he would almost exclusively use broken-into-parts problems and was not likely to use other problem types which may provide less support and create more of a challenge for the introductory physics students. Similarly, regarding the broken-into-parts problem type, another interviewed TA said: "I will use it everywhere." The idea of almost-exclusive preference for using this type of problem was conveyed by many other TAs during the interviews, as well as in written responses. Below, we discuss reasons behind the rankings and stated uses, based upon interview data and the written responses in the columns of the worksheet which asked for explanations and/or reasons for their responses.

FIG. 3: TAs reported usage of the broken-into-parts problem type. These are the reported usages as averaged over both types of the broken-into-parts problem type since there was no significant difference between the two broken-into-parts problem types. Light grey indicates the TAs who would only use this type of problem in homework. Dark grey indicates those who would use it in homework, quiz or exam. Medium grey indicates those who would use it in quiz or exam. Black indicates those who would *never* use it for any purpose.

TAs viewed the pro of guiding students as outweighing the con of providing too much help: The written pros and cons and explanations as well as the interview data were analyzed regarding the broken-into-parts problem type for possible reasons for why the TAs ranked the broken-into-parts problem type the way they did. Table I shows the most common pros and cons mentioned by TAs in written responses.

The most common pro stated for the broken-into-parts problem type was "guide," which was mentioned by 80% of TAs. "Guide" was the category used for TAs' responses which included what they judged to be an opportunity to guide the student in the problem solving process. Some examples include: "Guides students to understand how to solve the problem," and "Leads the student to solve the problem step-by-step."

By contrast, TAs did not list very many cons. Even though they were specifically asked to list at least one pro and one con, many TAs failed to list any cons for the broken-into-parts problem type completely. Table I shows that the only commonly stated con for the broken-into-parts Problems A and D was "help," and that this con was mentioned by only 37% of TAs. The category "help" contained TA responses in which the TA expressed concerns that breaking the problem into sub-problem for students may make this type of problem too easy (for example: "Not difficult enough" or "helping the student too much".

Although the con "help" suggests that some TAs had reservations about the broken-into-parts problem type potentially providing too much help to students, this con is mentioned by only about one-third of TAs in written response (even though students were asked to mention at least one con). Even in interviews, any con for broken-into-parts problems was rarely mentioned even when TAs were explicitly asked for at least one con. Both written and interview data suggest that the con "help" may not be viewed as a major drawback to TAs. Indeed, TAs were often reluctant to report downsides to broken-into-parts problem type, sometimes using superlative language to describe this type of problems. For example, several TAs went as far as to use the word "perfect" in describing broken-into-parts problems for homework, quizzes, and exams in introductory physics, apparently not detecting any drawbacks to this type of problems.

Although TAs mentioned the asset of a broken-into-parts problem type guiding the introductory physics students in solving the problem at hand, the nature of the responses did not usually indicate the idea that such problems could be used to train students to solve future problems that are not broken into parts. Furthermore, TAs rarely mentioned in interviews or written responses that the scaffolding support provided by these type of problems should gradually be removed to help students develop self-reliance in problem-solving.

IV. DISCUSSION AND SUMMARY

We find that most TAs highly valued broken-into-parts problem type and stated that they would use this problem type often on homework, quizzes, and exams because breaking the problem into sub-problem before posing it is needed for facilitating the problem-solving process for introductory students. Discussion during interviews suggests that TAs may overuse broken-into-parts problems partly due to their preference to guide introductory physics students through the problem-solving process. In the cognitive apprenticeship model, appropriate coaching and scaffolding support can help develop expertise and train a student to eventually gain independence in solving complex physics problems [22]. This type of long-term goal was not typically mentioned or implied by TAs' responses in written or interview data. Instead, the use of broken-into-parts problem type was regarded by TAs as beneficial and necessary for helping guide students in solving the problem at hand in most contexts and this pro alone appears to be a major reason for why the TAs were likely to frequently use broken-into-parts problems in homework, quiz and exam situations. However, TAs did not indicate that introductory students should also be given opportunity to practice more independent problem solving via problems in which the scaffolding support is removed after the modeling and coaching part of the cognitive apprenticeship process in order to develop self-reliance. While TAs' concern for students is good, if guidance in the problem solving process is not removed gradualy, introductory students may not learn to break a physics problem into sub-probles and solve the problem independently without support.

These findings partly agree with a similar study involving physics instructor's views of various problem types, in that, like instructors, TAs reported extensive use of broken-into-parts problems despite any reservations they might have about them [29]. However, the TAs appear to have an even stronger preference for broken-into-parts problem type than did the faculty in that fewer TAs expressed a concern that such problems may provide too much help to students (even when explicitly asked to state at least one con of a broken-into-parts problem type) compared with the number of faculty who expressed similar concerns. While nearly half of faculty identified independent problem solving without guidance as an important goal in teaching problem-solving [29], few TAs mentioned that using problems which do not provide introductory students with guiding support was important because they can help introductory physics students develop self-reliance in problem solving. Additionally, interviews and written data suggest that, even among those TAs who had a concern about a broken-into-parts problem potentially providing too much help, this concern was not strong and did not outweigh the benefit of guiding a student through a problem by breaking it into parts in homework, quizzes, and exams. Moreover, while both TAs and faculty reported copious use of broken-into-parts problems with their introductory students whether or not they had concerns about such problems, most TAs overlooked the need to challenge introductory students by offering them opportunities to solve problems which do not have the steps already broken-down for them so that they can develop expertise and self-reliance in problem-solving.

TAs' preference for continually providing problems for introductory students which are broken into parts represents an important oversight in the steps required for introductory students to learn independent expert-like problem-solving. In particular, introductory students must be given opportunities to practice bridging the gap between solving problems that are broken-into-parts and solving problems with less built-in support in order to develop robust problem solving, reasoning, and meta-cognitive skills, a point that most TAs appear to have missed.

Our study focused on physics recitations, however, breaking complex problems into simpler subproblems is an important skill in laboratory course contexts as well, so our findings may apply in those contexts also. A limitation to our findings may be that they are relevant to universities with similar physics graduate TA professional development, and may not apply to other institutions without such a professional development program for TAs. However, leaders of TA professional development programs can incorporate the findings of this study to help TAs elucidate appropriate teaching and learning goals for both introductory and advanced physics students that support student growth and learning and reflect on instructional approaches that support the goals.

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