Does using a visual-representation tool foster students' ability to identify forces and construct free-body diagrams?

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Earlier research has shown that after physics instruction, many students have difficulties with the force concept, and with constructing free-body diagrams (FBDs). It has been suggested that treating forces as interactions could help students to identify forces as well as to construct the correct FBDs. While there is evidence that identifying interactions helps students in quantitative problem solving, there is no previous research investigating the effect of a visual-representation tool—an interaction diagram (ID)—on students' ability to identify forces, and to construct the correct FBDs. We present an empirical study conducted in 11 Finnish high schools on students ($n = 335$, aged 16) taking their first, mandatory, introductory physics course. The study design involved groups of students having heavy, light, or no use of IDs. The heavy and light ID groups answered eight pairs of ID and FBD questions in various physical contexts and the no ID group answered two of the eight FBD questions. The results indicate that the heavy ID group outperformed both the light and the no ID groups in identifying forces and constructing the correct FBDs. The analysis of these data indicates that the use of IDs is especially beneficial in identifying forces when constructing FBDs.

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I. INTRODUCTION

A. Background and purpose of the research

The force concept is at the heart of Newton's laws of motion and is a central concept in the theory of classical mechanics that is taught from lower secondary school to university level. One important pictorial representation used in the teaching of forces is a free-body diagram (FBD), which depicts force vectors acting on a target object (some authors use the term force diagram). A FBD conveys much information. First, it keeps track of all forces and their relative magnitudes. Second, it allows for the deduction to be made as to whether the object has acceleration or not, as the sum of forces (i.e., net force) is directly related to acceleration via Newton's second law of motion. In addition, the direction of acceleration can be deduced, as Newton's second law is a vector equation. Third, motion can be determined if information on velocity and acceleration is supplied [1]. There are many papers in the literature on FBDs and on how to use them in teaching [2–13]. While useful, these papers do not evaluate student learning. In addition, there are studies reporting that students often have difficulties with constructing the correct FBDs [14–17]. Students' difficulties with FBDs are not surprising, as there is a substantial body of research showing that many students have difficulties with the force concept after instruction [18–22]. Furthermore, the vector concept underpinning the successful use of FBDs is challenging for introductory physics students [23–25].

Many researchers have suggested that teaching forces as interactions would be helpful in teaching the force concept [1,26–30]. One way to achieve this is by utilizing a visual-representation tool for visualizing interactions between objects. There are various ways of visualizing the objects and interactions between them: for instance, system schema [31–33], symbolic representations of interactions [29,34], system-interaction diagrams [35], and interaction diagrams (IDs) [36], which are used in our study. While there are differences between the aforementioned visualizations, we consider them as variants of the same representational tool, since each helps to identify and represent interactions between objects, thus helping students to perceive forces as the property of an interaction instead of a property of an object. There is good evidence that using a visual-representation tool such as the ID fosters students' conceptual understanding of Newton's third law [33,34,37–39]. Moreover, it is plausible that if a student identifies interactions correctly in a given situation when using the ID, the ID might also facilitate in the identification of forces acting on a target object, and, in this way, help students to construct an FBD.

There is some previous research showing that students' quantitative problem solving in the context of forces is enhanced when they are guided to identify forces by first identifying interactions [40,41]. In Heller and Reif's [40] study, students worked under external control (*not* a teaching situation). Students used a description protocol focusing on interactions when constructing FBDs, which were, in turn, used as an aid in forming equations. However, the assessment only considered the equations, and not the quality of the FBDs. The effect of the quality of FBDs

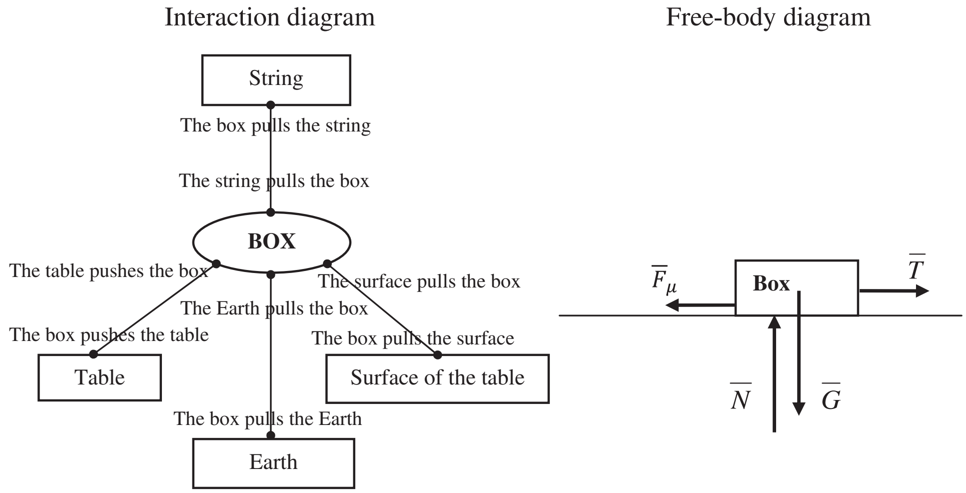

FIG. 1. The ID and the corresponding FBD when a box is pulled with a string along a table at constant velocity.

on problem solving has also been studied [41,42]: These studies showed that students who drew FBDs correctly were significantly more successful in quantitative problem solving than students who drew incorrect diagrams or who showed no evidence of using FBDs. On the other hand, the use of FBDs does not always support problem solving: Heckler [43] found that students who were *prompted* to use FBDs were less likely to obtain a correct solution than students who were not prompted to solve the problem in any particular way.

The studies by Rosengrant *et al.* [41] and Ayesh *et al.* [42] did not study the effect of a visual tool—such as the ID—on the quality of FBDs. We are not aware of any published evidence on the role of IDs in helping students, especially high school students, to identify forces and construct FBDs, although there is anecdotal evidence that system schemas are helpful in these respects [32]. Thus, our research questions are as follows (note that correct identification of forces is a necessary but not a sufficient condition for a correct FBD):

(1) Does using IDs help students to identify forces correctly?
(2) Does using IDs help students to construct the correct FBDs?

First, we discuss the ID used in this study and its relations with FBD. Second, we briefly discuss the teaching of the different groups participating in this study. Third, we analyze empirical data gathered from 11 Finnish high school teachers.

B. The interaction diagram and its relation to the free-body diagram

The ID shows both the target object and the objects interacting with it. However, it is important to note that the ID does not show the state of motion; it is indifferent with respect to constant velocity and acceleration situations because it does not contain any information on the magnitudes of forces. In contrast, the FBD shows only forces acting *on* the target object, and it is possible to deduce the state of motion by checking whether the sum of force vectors adds up to the zero vector or not. Figure 1 shows examples of an ID and corresponding FBD when a block is pulled with a string along a table at constant velocity.

The ID shows the interactions in terms of pushing and pulling. These interactions are written down to make the interactions explicit and to help students to see the connection between the ID and Newton's third law, which was expressed in this study in the following form (translated by author A. S.): "Force and opposite force are created from an interaction between two objects. The force and opposite force are equal in magnitudes but opposite in directions, and they act on different objects" [36]. Moreover, there is only one contact between the block and the table, but it is helpful to separate this contact interaction into two components, as is done in Fig. 1. This separation facilitates a complete correspondence with an FBD: The number of interaction lines or arrows corresponds with the number of forces in the FBD. This is a very important feature of the ID, as it allows a readily available way of checking that for each force there is a corresponding interaction. Hence, it is reasonable to assume that the likelihood of including extra forces in an FBD (such as an "impetus" force along the direction of motion) is diminished. In the same way, the ID has the potential of safeguarding missing force(s) in the FBD, provided that all relevant interactions are identified.

II. METHODS

A. Participants

The participants of this study consisted of three main groups of students (total $n = 335$, aged 16): *heavy use of IDs* ($n = 75$), *light use of IDs* ($n = 57$), and *no use of IDs* ($n = 203$). All groups participated in the first and only mandatory Finnish high school physics course, Physics 1, which involves only a minimum amount of algebra, and

TABLE I. Groups and students participating in the study ($n = 335$).

Group	Number of students
Heavy ID	75
Heavy ID 1	25
Heavy ID 2	27
Heavy ID 3	23
Light ID	57
Light ID 1	36
Light ID 2	21
No ID 1– 6	203

includes a general introduction to physics, elementary kinematics, the force concept, Newton's laws, the energy concept, waves and radiation, the basics of matter, fundamental interactions, and cosmology (teaching time is approximately 30 lessons of 45 min each, or 18 lessons of 75 min each, depending on the school timetable). There were three teachers from three different high schools teaching the heavy ID groups and two teachers from two different high schools teaching the light ID groups. The data concerning ID groups were gathered in fall 2006 and fall 2007. In addition, there were six teachers from five different schools teaching no ID groups; these data were gathered in fall 2012. All 11 teachers participating in this study were experienced teachers having at least nine years of teaching experience at the time of the study. All groups are presented in Table I.

We combined the heavy ID groups into a single heavy ID group, light ID groups into a single light ID group, and no ID groups into a single no ID group, as the main focus in this paper is in possible differences between different approaches regarding the ID, not in investigating the degree of success of individual teachers. Schools or students were not randomly selected for the study. However, we managed to incorporate different sized schools from cities and from the countryside. This provides some diversity in terms of settings in which the study was implemented.

B. Teaching the force concept

1. Heavy use of IDs

Heavy ID teachers were provided with intervention material for five lessons (1 lesson = 45 min) addressing the force concept and Newton's third, first, and second laws, in that order. We note that introducing Newton's third law before Newton's other laws is not typical in many introductory physics textbooks. The intervention material contained teaching and practice exercises introducing the ID, Newton's laws, and FBDs for the lessons and homework. The teachers received no special training whatsoever; instead, they were provided with the intervention material and a brief written description on how to implement their teaching. Some small group work requiring students to interact with each other was incorporated in the intervention description. The heavy ID teachers used the textbook *Physica 1*, which utilizes an ID approach, and thus supported the intervention material, providing additional practice on IDs and FBDs [36]. We have discussed in greater detail in our earlier research how the ID was used for introducing the force concept and teaching Newton's third law [38,39]. We present here the key activities in order to provide the reader with an idea of how the ID and FBDs were taught:

- Students work in pairs constructing IDs and identifying contact and distance interactions in three different situations.
- The force vector and FBD are introduced in terms of interaction force pairs, and the relationships *and* differences with the ID and the FBD are determined.
- Newton's third law is introduced: Interaction is symmetric regardless of the state of motion.
- Students draw FBDs for the ID exercises that they constructed previously.
- Newton's first (N1 law) and second laws (N2 law) were introduced using a (t, v) graph representing the velocity of a football (handout derived from [44]). Students used the graph as a basis for constructing IDs and FBDs in the different stages of motion. The laws were defined after an experiment on a cart in a linear air track.
- N1 and N2 laws were used to reexamine the earlier FBDs, which were constructed as a homework exercise.
- Students engaged with quantitative exercises on N1 and N2 laws using FBDs as a starting point.

Based on video recordings, the lecturing time related to FBDs varied between 20 and 26 min. In addition, some time—approximately 15 min—was used for student practice on FBDs during the lessons.

2. Light use of IDs

The light ID teachers also used *Physica 1*, which follows approximately the same order as the intervention material in introducing forces as interactions and the ID approach:

- The notions of interaction and the ID are introduced with examples and exercises.
- Newton's third law is introduced in terms of interaction force pairs.
- Different types of forces are discussed, with examples and exercises on forces and Newton's third law.
- The FBD is introduced and explicitly compared with IDs.
- Newton's first and second laws are introduced with the help of FBDs.

As already explained, both heavy and light ID groups used the same textbook, *Physica 1*, but only the heavy ID group followed the intervention material on how to integrate the ID into teaching. Furthermore, the intervention material in the heavy ID group contained many exercises addressing the ID. In contrast, teachers in the light ID group reported that they presented only one example of an ID and then their students constructed the ID during two or three exercises. Moreover, the light ID group teachers estimated that they had taken 20 min to lecture on FBDs, and, that about 15 min was used for student practice on constructing FBDs. The total time spent on teaching the force concept (testing time not included) was about four lessons, whereas in the heavy ID group it was five lessons.

3. No use of IDs

The textbook followed by the no ID group introduces forces as interactions and Newton's third law before Newton's other laws [45]. This textbook explains the role of interaction carefully and the explanation is accompanied by pictures showing force vectors acting on objects participating in interaction. The idea of the FBD is introduced in this phase, although no explicit instructions on how to construct FBDs are provided. There are several exercises addressing interactions and Newton's third law force pairs using vectors. N1 and N2 laws are introduced using several FBDs. The main difference between the textbooks used in the heavy and light ID groups and the no ID group is that the latter does not use IDs at all.

All teachers, except for one in the no ID group, reported that they introduced forces in terms of interactions. The reported times for teaching FBDs varied considerably: from 15 to 40 min, the average being 26 min, including student practice time during the lessons. This suggests that the no ID group spent less time, on average, with the FBDs than the heavy ID groups. However, the times are relatively short in all groups. This is probably due to the nature of the course: Physics 1 is an introductory course with a very wide range of topics.

C. Data collection

Eight test questions on the ID and FBDs (Table II) were administered to the heavy and light ID groups. The questions addressed various physical situations and states of motion, as there is evidence that student understanding is context dependent [46–48]. The questions were posed using pictorial representation together with the verbal description of the situation. The heavy and light ID students were required to construct both the ID and the FBD in each situation. The no ID group answered two FBD questions at the end of Physics 1: "a book on the table" and "a girl in an elevator going down" (see Table II; three examples are provided in Fig. 2, see the Appendix). The no ID group did not answer any ID questions, since the students were not familiar with the notion of an ID. In addition, all groups answered several questions on Newton's third law; these data are discussed elsewhere [38,39].

Heavy ID teachers' teaching activities were video recorded in the intervention lessons (with one exception: recording failed in one lesson in one school due to a technical problem). The video material was analyzed by using the ATLAS.TI and EXCEL softwares. Some important episodes were transcribed since we were interested in what kind of classroom discourse the teachers used: the findings have been published elsewhere [49].

The heavy ID groups took the Force Concept Inventory (FCI) as a pretest [50,51]. The FCI does not address FBDs, but it includes seven questions (items 3, 5, 11, 13, 18, 29, 30) explicitly requiring the identification of forces. These questions are of special interest, as our first research question addressed students' ability to identify forces. However, we did not administer the pre-FCI test to the light or no ID groups to keep the testing time for these groups as low as possible. This *could* potentially threaten our study design: Perhaps the heavy ID group was significantly different to the light or no ID groups in their initial ability to identify forces, as they had encountered some instruction on forces prior to entering the first high school course. We, however, disregard this, because there is an abundant body of research showing that students do not typically understand the force concept without the interactive-engagement type of teaching [52].

Sixteen heavy ID group students from three different schools also continued studying forces using IDs in the second-year course on mechanics. The second-year course included much more problem solving than Physics 1, and included the usual topics of kinematics, forces, Newton's

TABLE II. Post-test tasks on the interaction diagram and FBDs for the heavy and light ID groups.

Moment in teaching	Context	State of motion
After teaching the ID and FBD	Parachuter going down	Uniform motion
	Cork floating in water	At rest
After completing teaching of the force concept	Book on a table	At rest
	Box lowered down by a rope	Uniform motion
	A girl in an elevator going down	Downward acceleration
As a part of the final exam	Ice hockey puck hit	Acceleration
	Ice hockey puck sliding	Deceleration
	Ice hockey puck on ice	At rest

TABLE III. The classification of the quality of students' interaction diagrams.

Excellent	Good	Poor
All interacting objects identified.	All interacting objects identified.	At least one interaction is missing or an extra interaction is included.
Interaction line or two-headed arrow presented.	Interaction line or two-headed arrow presented.	*or*
Type of interaction (contact or distance) identified.	Type of interaction is not presented.	Forces are identified instead of interactions.
or	*and*	*or*
A written explanation of interactions is presented.	No written expression of the interactions is presented.	Diagram lacks essential features of an interaction diagram.

laws, conservation of momentum, and conservation of energy. The level of treatment is quite similar to Giancoli's [53] algebra-trigonometry-based textbook. These students took the post-FCI test, allowing for the determination of the normalized gain in the force-identification questions. We are aware that Hestenes and Halloun [54] have argued that the entire FCI test should be used for the purposes of course and teaching evaluation. However, we have provided evidence in our earlier study that analyzing the dimensions of the force concept addressed in the FCI can also provide useful information on students' learning [55].

D. Data analysis

1. Quality analysis of interaction and free-body diagrams

The IDs and corresponding FBDs were analyzed and classified into three quality categories: excellent, good, and poor (Tables III and IV, respectively). The Kappa statistic was evaluated by the authors A. M. and A. S. to determine consistency among the raters. Fifteen students were randomly selected: The total number of ID and FBD pairs analyzed was 117.

2. Force Concept Inventory data

As already pointed out, the pre-FCI data on seven questions identifying forces are used to compare the initial knowledge state of three schools in the heavy ID group. We use the average normalized gain as a measure in gauging the change in the seven FCI questions on identifying forces for the 16 students who took both the pre- and post-FCI test. The average normalized learning gain is defined as the ratio of the actual gain to the maximum possible gain [52]:

$$G = \frac{\text{post-test}\,\%\text{–pretest}\,\%}{100\%\text{–pretest}\,\%}$$

III. RESULTS

A. Interaction and free-body diagrams

1. Quality of interaction and free-body diagrams

The results regarding the quality of students' IDs and FBDs are shown in Tables V and VI. We stress here that we are not concerned with a student as a statistical unit. Instead, an ID and FBD pair generated from the eight questions (Table II) is the statistical unit: A total of 553 pairs was constructed by the heavy ID group ($n = 75$) and 412 pairs by the light ID group ($n = 57$). We included all cases when a student answered both the ID and FBD in a given situation. Not all students answered all eight questions, but most students answered all the questions. The interrater reliability for the raters in the case of IDs was found to be Kappa $= 0.958$ ($p < 0.001$) and in the case of FBDs, Kappa $= 0.855$ ($p < 0.001$), both indicating excellent agreement.

TABLE IV. The classification of the quality of students' free-body diagrams.

Excellent	Good	Poor
Forces are identified correctly.	Forces are identified correctly.	At least one force is missing or extra forces are included.
and	*and*	*or*
Forces are presented as vectors.	Forces are presented as vectors.	The direction of the force vector is incorrect.
and	*and*	*or*
Forces are properly labeled or named.	Forces are not labeled or named.	Lines are used instead of vectors or only a written explanation is used.
and	*or*	*or*
The vector sum of the forces is correct within 2 mm.	The vector sum of the forces is not correct within 2 mm.	FBD is otherwise unclear.

TABLE V. Crosstab for the ID + FBD pairs in the heavy ID group. The number of pairs is reported in parenthesis.

	Poor FBD	Good FBD	Excellent FBD	ID sums
Poor ID	11.4% (63)	2.4% (13)	3.1% (17)	16.8% (93)
Good ID	5.1% (28)	11.6% (64)	9.9% (55)	26.6% (147)
Excellent ID	10.5% (58)	16.5% (91)	29.7% (164)	56.6% (313)
FBD sums	26.9% (149)	30.4% (168)	42.7% (236)	100% (553)

TABLE VI. Crosstab for the ID + FBD pairs in the light ID group. The number of pairs is reported in parenthesis.

	Poor FBD	Good FBD	Excellent FBD	ID sums
Poor ID	28.6% (118)	6.6% (27)	8.3% (34)	43.4% (179)
Good ID	11.2% (46)	7.3% (30)	12.4% (51)	30.8% (127)
Excellent ID	9.5% (39)	9.2% (38)	7.0% (29)	25.7% (106)
FBD sums	49.3% (203)	23.1% (95)	27.7% (114)	100% (412)

The χ^2 test was conducted using the observed frequencies (not the percentages). The p value of ≤ 0.05 was considered as statistically significant. The effect size was estimated using Cramer's V where $0.1 =$ small effect, $0.3 =$ medium effect, and $0.5 =$ large effect [56]. The χ^2 test showed that the quality of IDs was related to the quality of the FBDs in both groups [$\chi^2(4) = 106.72$, $p < 0.001$; Cramer's $V = 0.31$ in Table V and $\chi^2(4) = 42.32$, $p < 0.001$; Cramer's $V = 0.23$ in Table VI]. The effect sizes indicate medium and small effects in Tables V and VI, respectively. The effect sizes suggest that the association with the quality of IDs and FBDs was stronger in the heavy ID group than in the light ID group.

The no ID group answered two post-test FBD questions. The results regarding these two FBDs for all three groups are presented in Table VII. The χ^2 test showed that the quality of FBDs had an association with the group [$\chi^2(4) = 84.76$, $p < 0.001$; Cramer's $V = 0.26$]. The pairwise comparisons are given in Sec. III B.

2. Interaction diagrams and identification of forces

Good or excellent ID provides a criterion for the correct identification of all interacting objects (Table III) and good or excellent FBD provides a criterion for the correct identification of forces (Table IV). Using the former criterion shows that the interactions were correctly identified in 83.2% of all IDs (460 IDs with correctly identified interactions out of all 553 IDs) in the heavy ID group and in 56.3% of all IDs (233 IDs with correctly identified interactions out of all 412 IDs) in the light ID group. Subsequently, using both criteria reveals that correct identification of the interactions resulted in the correct identification of forces in 81.3% of the cases (the *intersection* between correctly identified interactions and correctly identified forces is 374; this leads to 374 out of 460, which gives 81.3%) in the heavy ID group and in 63.5% of the cases (now the intersection is 148 out of 233) in the light ID group. Conversely, 18.7% of the FBDs (86 out 460) in the heavy ID group and 36.5% in the light ID group (85 out of 233) were poor when the interacting objects were correctly identified. The figures are almost the same when only excellent IDs are considered (18.6% and 36.8%, respectively). Furthermore, it was possible to identify forces correctly without correctly identifying the corresponding interactions: this took place in only 7.4% of the cases (30 out of 404 good or excellent FBDs) in the heavy ID group. However, the corresponding figure in the light ID group was much higher (29.2%; 61 out of 209). These results support that the association of the quality of IDs is indeed stronger in the heavy ID group than in the light ID group.

TABLE VII. Crosstab for the two FBD questions in three groups. The number of FBDs is reported in parenthesis.

	Poor FBD	Good FBD	Excellent FBD
Heavy ID group	19.3% (26)	37.8% (51)	43.0% (58)
Light ID group	51.5% (52)	15.8% (16)	32.7% (33)
No ID group	62.0% (241)	22.9% (89)	15.2% (59)

We checked cases when a student included one or more extra forces, or missed at least one force in his or her FBD (the poor FBD class also contained other types of mistakes, as explained earlier). An extra force or a missed force was included in 21.7% of all FBDs in the heavy ID group and in 44.7% in the light ID group, indicating that most cases in both groups in the poor FBD category had these mistakes; overall, 26.9% of the FBDs in the heavy ID group and 49.3% in the light ID group were poor.

The no ID group managed to identify forces correctly in 38.1% of the cases, whereas the corresponding percentage for the same two questions for the heavy and light ID groups were 80.8% and 48.5%, respectively. Furthermore, extra or missing forces were present in 57.6% of the FBDs in the no ID group. The differences between the heavy and no ID groups are especially clear.

3. Interaction diagrams and correct free-body diagrams

In correct FBDs, the forces were correctly identified *and* the vector sum corresponded with the state of motion in a given situation (i.e., an excellent FBD in our classification). The latter criterion means that a correct FBD requires that Newton's first or second law was correctly taken into account. The fraction of correct FBDs from all FBDs in the heavy and light ID groups was 42.7% and 27.7%, respectively. Furthermore, 92.8% of excellent FBDs (219 out of 236) in the heavy ID group were associated with the correct identification of interactions (i.e., good or excellent IDs); in the light ID group the fraction was 70.2% (80 out of 114). An excellent ID was not a sufficient condition for a correct FBD: Only 52.4% of excellent IDs (164 out of 313) in the heavy ID group and 27.4% (29 out of 106) in the light ID group resulted in correct FBDs.

The no ID group only had correct FBDs in 15.2% of the cases, whereas the corresponding percentage for the same two questions for the heavy ID group was 43.0%, and for the light ID group, 32.7%. It appears that the no ID group had far fewer correct FBDs than the heavy and light ID groups.

B. Statistical comparisons between the groups and schools

We compared the performance between the groups (again, the statistical unit is a test item, not a student's score). The comparisons are presented in Table VIII. Note that the comparisons between heavy and light groups were based on eight questions, whereas the comparisons with the no ID group were based on two questions, as explained earlier. All differences are statistically significant and the effect sizes indicate small or medium effects. The heavy ID group had the best performance and the no ID group was outperformed by both the heavy and light ID groups.

We also compared the three schools within the heavy ID group and the two schools within the light ID group. There were no statistically significant differences in the FBDs between the heavy ID schools [$\chi^2(4) = 9.24$, $p = 0.055$; Cramer's $V = 0.091$]. However, we found a statistically significant difference in the IDs [$\chi^2(4) = 238.43$, $p < 0.001$; Cramer's $V = 0.46$] between heavy ID schools. Pairwise comparisons revealed that heavy ID school 2 differed from the other two schools. One possible explanation for the difference was found by inspecting the video recordings. The teacher in heavy ID school 2 did not include written interaction forces or an interaction type in the IDs (see Fig. 1). It seems that most students followed the teacher's examples instead of those from the textbook (*Physica 1*), and, consequently, entered the "good" quality category instead of the "excellent" category with their IDs. However, the teacher did explain the IDs in terms of interaction force pairs.

There was no statistically significant difference in the FBDs between the two light ID schools [$\chi^2(4) = 2.63$, $p = 0.27$; Cramer's $V = 0.080$]. However, there was a statistically significant difference in the IDs ($\chi^2 = 136.01$, $p < 0.001$; Cramer's $V = 0.57$). These data indicate that the teacher in the other light ID school succeeded better in teaching the IDs, especially because the effect size was large. Regrettably, we did not have videos on the light ID groups to investigate this matter further, as we did in the case of the heavy ID school. Interestingly, the clear difference in the IDs was not reflected as a different performance in the FBDs. This suggests that the relationship between IDs and FBDs is not straightforward.

There were statistically significant differences in the FBDs between six classes in the no ID group [$\chi^2(10) = 34.12$, $p < 0.001$; Cramer's $V = 0.21$]. The difference was thought to be due to the teachers using varying amounts of time (15 to 40 min) when teaching the FBD aspect. However, the effect size was small.

TABLE VIII. Statistical comparisons between the groups in terms of quality of IDs and FBDs.

Comparison	χ^2	p value	Cramer's V	Effect
Heavy–light (IDs)	112.72	<0.001	0.34	Medium
Heavy–light (FBDs)	51.57	<0.001	0.23	Small
Heavy–no ID (FBDs)	78.86	<0.001	0.39	Medium
Light–no ID (FBDs)	16.41	<0.001	0.18	Small

C. FCI questions on force identification

The pre-FCI test was administered only to the heavy ID group ($n = 74$; one student was absent). Their pretest average in seven force-identification questions was 25.5%, which is just above the level of guessing (20%), as expected. As we anticipated, there were no statistically significant differences between the heavy ID schools in the seven force-identification questions. The 16 students who completed the post-FCI test in the following year had a pretest average of 26.8% in the force-identification questions, which is very close to the average of the whole group. These results and earlier findings on the FCI [52] support the fact that there is no reason to suspect that the light ID group or no ID group would have had significantly different pre-FCI results in this regard.

The post-FCI average in the force-identification questions for the 16 students was 71.4%, which gives a normalized gain of 0.61, indicating quite a good learning gain in this conceptual domain. This result concurs with the results above: Students' ability to identify forces was fostered in courses systematically using the ID approach.

IV. DISCUSSION AND CONCLUSIONS

Our first research question asked whether using IDs helps students to identify forces when constructing FBDs. The answer is positive, since the correct identification of interactions resulted in the correct identification of forces in both heavy and light ID groups in the majority of cases (81.3% and 63.5%, respectively). On the other hand, correct identification of interacting objects in an ID did not always result in correct force identification, especially in the light ID group, and there were cases when the forces were correctly identified in the FBD although the corresponding IDs were poor. This discrepancy is expected to some extent. While being closely related, constructing IDs and FBDs entails different skills, for instance, the direction of a force vector cannot be deduced using only information embodied by the ID. Some students had included reaction forces in their FBDs; these were counted as extra forces. Hence, it appears that these students had difficulties to differentiate between IDs and FBDs. It is also possible that some students viewed constructing IDs and FBDs as separate tasks having little to do with each other. These difficulties should be taken into account in teaching: Care should be taken to help students to see how these two representational tools are related to each other, and how they differ from each other. To sum up, these results could be interpreted as follows: The *likelihood* of the correct identification of forces in an FBD is relatively high *if* the student has identified interactions correctly in an ID. Furthermore, the FCI data (though data were available only for 16 students) support that the ID approach also fostered students' ability to identify forces in contexts other than the FBD. In addition, the heavy ID group clearly outperformed the no ID group in identifying forces in two questions, providing further support that the use of IDs is useful in this respect.

Our second research question asked whether the use of IDs helps students to construct correct FBDs. The results were less clear on this question. Although the majority of correct FBDs in both heavy and light ID groups (92.8% and 70.2%, respectively) were associated with correct identification of interacting objects, the converse was not true: The correct identification of interacting objects resulted in a correct FBD in about half the cases for the heavy ID group, and in a quarter of cases in the light ID group. From the point of view of physics, identifying interacting objects is a necessary, but not a sufficient condition for constructing correct FBDs: Newton's first or second law must also be correctly applied. Interestingly, these conditions are reflected in our data, as the correct identification of forces did not guarantee correct FBDs. On the other hand, the results in the no ID group (only 15.2% of FBDs were correct in the two questions) suggest that both heavy and light ID groups had a fostered learning outcome in constructing correct FBDs. Considering all the evidence, we conclude that the use of IDs is beneficial in constructing correct FBDs, although the relationship with the quality of IDs was not straightforward in this regard.

The results indicate that the heavy ID group outperformed the light ID group in both IDs and FBDs, and that there was a stronger association with the quality of IDs and correct FBDs in the heavy ID group than in the light ID group. These results are very likely due to the systematic use of IDs and explicit linking of the IDs and FBDs in the heavy ID group. The light ID group was exposed to the IDs only a few times during the teaching phase. However, it is possible, and even likely that constructing the eight test IDs provided an additional learning experience to the light ID group, although the students did not get feedback as to how they had fared in the tests.

There were some differences between the schools within heavy and light ID groups regarding the results of the IDs. These differences were not, however, accompanied with statistically significant differences in the FBDs. This further supports that the relationship between the performance in the IDs and FBDs is not straightforward.

It is plausible to expect that more time spent on any topic—e.g., in teaching how to construct FBDs—would yield better learning outcomes. On the other hand, in the light of earlier research reviewed in the Introduction, it is not likely that *just* more time devoted to, say, passive lecturing, would significantly change learning outcomes. We note that the time difference was already built into the study design: We aimed to find out what would happen when the ID received heavy (i.e., more time and more examples) and light emphasis (i.e., less time and less examples). One can argue that the extra time investment in the IDs is quite moderate (at most 1 lesson or 45 min), especially when our data suggest that this extra time devoted to IDs is well warranted. This is further supported by the findings related to the enhanced learning outcomes of Newton's third law when the IDs are systematically used [38,39]. Moreover, the notion of interaction underpins the force concept and Newton's laws forming the basis of any scientifically correct treatment in this domain, which further justifies the use of extra time. The upshot is that it is the teacher's choice as to how much time she or he wants to devote to this topic. We believe that now there is evidence allowing the teacher to make an informed decision.

As already pointed out, there were no statistically significant differences in learning outcomes regarding the FBDs between the heavy ID teachers, which suggest that all three teachers were able to reap the benefits of using the ID approach. This result concurs with Hoellwarth and Moelter's [57] conclusion: Their study of an introductory physics course at university level showed that the structure of a course was important in promoting student learning, and not the characteristics of instructors who implemented the course. We also note that the heavy ID teachers did not receive any special training: they were just provided with the lesson plans and exercises to be used with the students. This shows that disseminating the ID approach can be quite easy. However, all ID teachers were familiar with the textbook utilizing the IDs and had used it several times previously. This provided them with the background to implement the designed teaching sequence—it might take more time for teachers who have never used the ID before, first, to see the worth of the ID approach, and second, to implement the approach effectively in their teaching. Furthermore, we are confident that the ID approach is accessible to physics instructors also in countries other than Finland, although this study was conducted in the context of the Finnish high school.

Earlier research has provided evidence that the ability to construct correct FBDs is related to successful quantitative problem solving in the domain of forces [41,42]. Our research complements the aforementioned findings by providing evidence that using IDs is especially beneficial in identifying forces when constructing FBDs.

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APPENDIX

In this Appendix we provide three examples on the ID and FBD exercises.

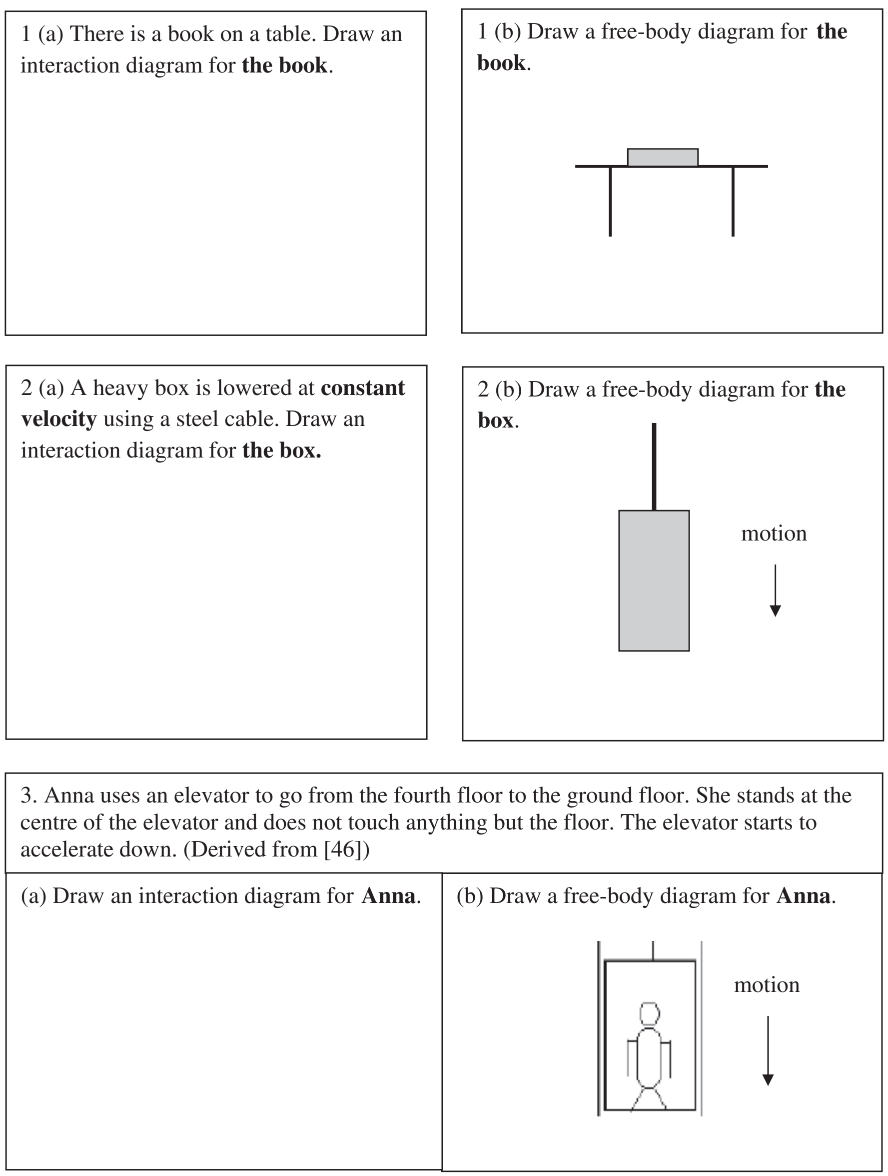

FIG. 2. Three examples on ID and FBD exercises.

[1] F. Reif, Millikan Lecture 1994: Understanding and teaching important scientific thought processes, Am. J. Phys. **63**, 17 (1995).
[2] E. van den Berg and C. van Huis, Drawing forces, Phys. Teach. **36**, 222 (1998).
[3] P. Wendel, Adding value to force diagrams: Representing relative force magnitudes, Phys. Teach. **49**, 308 (2011).
[4] W. Sperry, Placing the forces on free-body diagrams, Phys. Teach. **32**, 353 (1994).
[5] M. Mattson, Getting students to provide direction when drawing free-body diagrams, Phys. Teach. **42**, 398 (2004).
[6] R. Newburgh, Force diagrams: How? and why?, Phys. Teach. **32**, 352 (1994).
[7] A. Puri, The art of free-body diagrams, Phys. Educ. **31**, 155 (1996).
[8] L. G. Mathot, Free-body diagrams, Phys. Teach. **31**, 390 (1993).
[9] B. Lane, Why can't physicists draw FBDs?, Phys. Teach. **31**, 216 (1993).
[10] B. Lane, Response to Mathot, Phys. Teach. **31**, 390 (1993).
[11] J. E. Court, Free-body diagrams, Phys. Teach. **31**, 104 (1993).
[12] J. E. Court, Free-body diagrams revisited–I, Phys. Teach. **37**, 427 (1999).
[13] J. E. Court, Free-body diagrams revisited–II, Phys. Teach. **37**, 490 (1999).
[14] T. J. McCarthy and T. Goldfinch, Teaching the concept of free body diagrams, in *The 21st Annual Conference for the Australasian Association for Engineering Education, Sydney, 2010*, edited by A. Gardner and L. Jolly (The Faculty of Engineering & Information Technology, University of Technology, Sydney, Australia, 2010), pp. 454–460.
[15] R. E. Scherr and E. F. Redish, Newton's zeroth law: Learning from listening to our students, Phys. Teach. **43**, 41 (2005).
[16] P. Whiteley, Using free body diagrams as a diagnostic instrument, Phys. Educ. **31**, 309 (1996).
[17] J. Clement, Students' preconceptions in introductory mechanics, Am. J. Phys. **50**, 66 (1982).
[18] D. Watts and A. Zylbersztajn, A survey of some children's ideas of force, Phys. Educ. **16**, 360 (1981).
[19] I. Halloun and D. Hestenes, Common sense concepts about motion, Am. J. Phys. **53**, 1056 (1985).
[20] D. Hestenes, M. Wells, and G. Swackhamer, Force Concept Inventory, Phys. Teach. **30**, 141 (1992).
[21] A. Savinainen and P. Scott, Using the Force Concept Inventory to monitor student learning and to plan teaching, Phys. Educ. **37**, 53 (2002).
[22] D. T. Brookes and E. Etkina, "Force," ontology, and language, Phys. Rev. ST Phys. Educ. Res. **5**, 010110 (2009).
[23] S. Flores, S. E. Kanim, and C. H. Kautz, Student use of vectors in introductory mechanics, Am. J. Phys. **72**, 460 (2004).
[24] S. Flores-García, L. L. Alfaro-Avena, and O. Dena-Ornelas, Students' understanding of vectors in the context of forces, Rev. Mex. Fis. E **54**, 7 (2008), http://www.scielo.org.mx/pdf/rmfe/v54n1/v54n1a2.pdf.
[25] N. Nguyen and D. E. Meltzer, Initial understanding of vector concepts among students in introductory physics course, Am. J. Phys. **71**, 630 (2003).
[26] D. E. Brown, Students' concept of force: The importance of understanding Newton's third law, Phys. Educ. **24**, 353 (1989).
[27] C. Hellingman, Do forces have twin brothers?, Phys. Educ. **24**, 36 (1989).
[28] C. Hellingman, Newton's third law revisited, Phys. Educ. **27**, 112 (1992).
[29] J. D. Jimênez and F. J. Perales, Graphic representation of force in secondary education: Analysis and alternative educational proposals, Phys. Educ. **36**, 227 (2001).
[30] A. Van Heuvelen, Overview, case study physics, Am. J. Phys. **59**, 898 (1991).
[31] D. Hestenes, Modeling methodology for physics teachers, AIP Conf. Proc. **399**, 935 (1997).
[32] L. Turner, System schemas, Phys. Teach. **41**, 404 (2003).
[33] B. Hinrichs, Using the system schema representational tool to promote student understanding of Newton's third law, AIP Conf. Proc. **790**, 117 (2005).
[34] A. Savinainen, P. Scott, and J. Viiri, Using a bridging representation and social interactions to foster conceptual change: Designing and evaluating an instructional sequence for Newton's third law, Sci. Educ. **89**, 175 (2005).
[35] A. Tiberghien, J. Vince, and P. Gaidioz, Design-based research: Case of a teaching sequence on mechanics, Int. J. Sci. Educ. **31**, 2275 (2009).
[36] J. Hatakka, H. Saari, J. Sirviö, J. Viiri, and S. Yrjänäinen, *Physica 1* (Werner Söderström Oy Porvoo, Finland, 2004).
[37] P. Nieminen, A. Savinainen, and J. Viiri, Force Concept Inventory-based multiple-choice test for investigating students' representational consistency, Phys. Rev. ST Phys. Educ. Res. **6**, 020109 (2010).
[38] A. Savinainen, A. Mäkynen, P. Nieminen, and J. Viiri, "The effect of using a visual representation tool in a teaching-learning sequence for teaching Newton's third law" (unpublished).
[39] A. Savinainen, A. Mäkynen, P. Nieminen, and J. Viiri, An intervention using an interaction diagram for teaching Newton's third law in high school, in *Physics Alive: Proceedings of the GIREP-EPEC 2011 Conference*, edited by A. Lindell, A-L Kähkönen, and J. Viiri (University of Jyväskylä, Jyväskylä, 2012), pp. 123–128.
[40] J. I. Heller and F. Reif, Prescribing effective human problem-solving processes: Problem solving in physics cognition and instruction, Cogn. Instr. **1**, 177 (1984).
[41] D. Rosengrant, A. Van Heuvelen, and E. Etkina, Do students use and understand free-body diagrams, Phys. Rev. ST Phys. Educ. Res. **5**, 010108 (2009).
[42] A. Ayesh, N. Qamhieh, N. Tit, and F. Abdelfattah, The effect of student use of the free-body diagram representation on their performance, Educ. Res. **1**, 505 (2010), http://interesjournal.org/ER/pdf/2010/November/Ayesh%20et%20al.pdf.
[43] A. F. Heckler, Some consequences of prompting novice students to construct force diagrams, Int. J. Sci. Educ. **32**, 1829 (2010).
[44] Physics and Everyday Thinking (PET), http://petproject.sdsu.edu/assets/C2A1.pdf.

[45] H. Lehto, R. Havukainen, J. Maalampi, and J. Leskinen, *Fysiikka 1* (Sanoma Pro, Helsinki, 2011).

[46] L. Bao, D. Zollman, K. Hogg, and E. F. Redish, Model analysis of fine structures of student models: An example with Newton's third law, Am. J. Phys. **70**, 766 (2002).

[47] D. Palmer, The effect of context on students' reasoning about forces, Int. J. Sci. Educ. **19**, 681 (1997).

[48] R. Steinberg and M. Sabella, Performance on multiple-choice diagnostics and complementary exam problems, Phys. Teach. **35**, 150 (1997).

[49] N. Nurkka, A. Mäkynen, J. Viiri, A. Savinainen, and P. Nieminen, Classroom discourse types and students' learning of an interaction diagram and Newton's third law, in *E-Book Proceedings of the ESERA 2011 Conference: Science learning and Citizenship, Part 6*, edited by C. Bruguière, A. Tiberghien, and P. Clément (European Science Education Research Association, Lyon, France, 2012), pp. 58–64.

[50] I. Halloun, R. R. Hake, E. P. Mosca, and D. Hestenes, Force Concept Inventory, revised 1995, http://modeling.asu.edu/R&E/Research.html (password protected).

[51] I. Koponen, J. Jauhiainen, and J. Lavonen, A Finnish translation of the 1995 version of the Force Concept Inventory, Department of Physics, University of Helsinki, 2000, available upon request.

[52] R. Hake, Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses, Am. J. Phys. **66**, 64 (1998).

[53] D. Giancoli, *Physics—Principles with Applications* (Pearson Education, Inc., Upper Saddle River, NJ, 2005), 6th ed.

[54] D. Hestenes and I. Halloun, Interpreting the Force Concept Inventory, Phys. Teach. **33**, 502 (1995).

[55] A. Savinainen and J. Viiri, The Force Concept Inventory as a measure of students' conceptual coherence, Int. J. Sci. Math. Educ. **6**, 719 (2008).

[56] D. Clark-Carter, *Qualitative Psychological Research: A Student's Handbook* (Psychology Press, Hove, U.K., 2010), p. 301.

[57] C. Hoellwarth and M. J. Moelter, The implications of a robust curriculum in introductory mechanics, Am. J. Phys. **79**, 540 (2011).