Free-Body Diagrams and Problem Solving in Mechanics: An Example of The Effectiveness of Self-Constructed Representations

Vanes Mešić[1]
Sabaheta Mahmutović[1]
Elvedin Hasović[1]
Nataša Erceg[2]

[1]Faculty of Science, University of Sarajevo, Sarajevo, Bosnia and Herzegovina
vanes.mesic@gmail.com

[2]Department of Physics, University of Rijeka, Rijeka, Croatia

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Abstract
Earlier research has found that it is useful to distinguish situations in which students construct external representations on their own from situations in which they are expected to interpret already provided external representations. One type of representations that is particularly important for teaching mechanics is the free-body diagram. In this study, we investigated how inclusion of free-body diagrams into problem statements influences students' performance in solving mechanics problems. To that end two versions of a five-problem assessment instrument that only differed with respect to the inclusion/non-inclusion of free-body diagrams (FBDs) were administered to two groups of first year physics students. It was found that inclusion of free-body diagrams into the problem statements not only did not facilitate problem solving, but also impeded it significantly. Particularly large between group differences, in favor of the group not provided with FBDs, were detected for problems that required use of free-body diagrams showing resolution of forces into components. The results of our study indicate that consistency between internal and external representations of knowledge is a very important requirement for effective problem solving and effective learning of physics, in general. This consistency is most easily established when students use self-constructed external representations.
Keywords: free-body diagrams, self-constructed representations, problem solving, cognitive load, mechanics

INTRODUCTION

Today, there is a consensus in the scientific community that, in most contexts, individuals only can learn by putting mental efforts into the process of knowledge construction, whereby the learning process is largely based on the individual's foreknowledge (Bransford, Brown, & Cocking, 2000). Consequently, knowledge cannot be simply transmitted from the instructor's mind to the students' minds. However, this certainly does not imply that the characteristics of the environment do not influence an individual's learning, at all. As a matter of fact, most learning happens through an individual's interaction with the environment. At the very heart of this interaction is the process of representing and communicating information. The diverse forms in which information can be understood and communicated are called representations (see Meltzer, 2002). According to Lemke (as cited in Brookes & Etkina, 2007), students' primary activity in physics classes boils down to representing, i.e., interpreting and creating representations. It is important to distinguish situations in which students construct external representations on their own from situations in which they are expected to interpret already provided external representations (Cox, 1999; Wetzels, Kester, & Merrienboer, 2010). As a matter of fact, the teacher can use multiple representations in order to attempt to facilitate the process of co-construction of knowledge (Woolfolk, 2013). Thereby, the external representations are supposed to facilitate bridging from students' foreknowledge structures to target knowledge structures. It should be noted that in such case, the teacher is the person who largely makes the decision about ways how to get from the foreknowledge to the target knowledge structures and learning is largely influenced by the effectiveness of students' interpretation/assimilation of external knowledge that is provided by the teacher. An alternative is to create more opportunities for self-regulated learning (Woolfolk, 2013). In self-regulated learning the learner takes responsibility for setting learning goals and mobilizing resources and efforts needed to reach these goals, whereas co-construction of knowledge is characterized by interactions and negotiations between people with the aim of creating an understanding or solving a problem (Woolfolk, 2013). Knowledge that is figured out by the learner herself/himself is called self-constructed knowledge and is distinguished from socially constructed knowledge (Schweder, 1982). In co-construction, as well as in self-construction of knowledge, learning can be potentially facilitated by external representations, whereby in the self-construction approach students are to a greater extent expected to create the representations on their own instead of only interpreting the representations provided by the teacher. Generally, external representations are supposed not only to provide key information necessary for knowledge construction, but also to reduce cognitive load by allowing processing in the coupled system of internal and external representations (Nersessian, 2008).

According to Ainsworth (2008) combinations of multiple external representations can be used for: provision of complementary information, constraint of interpretation and construction of deeper understanding. However, if the provided external representations are perceived by the students as unfamiliar and/or too complex, then learning even can be impeded (Kohl, 2007; Wetzels, Kester, & Merrienboer, 2010). As a matter of fact, Cox (1999) points out that the effectiveness of reasoning with external representations depends on the interaction of three factors: semantic and cognitive properties of the representation, match between demands of task and information provided by the representation, and within-subject factors such as prior knowledge and cognitive style.

Creation and use of external representations is considered to be very important for problem solving (Kohl, 2007; Zou, 2000). Earlier research showed that expert and novice problem solvers largely differ with respect to their usage of external representations (see Zou, 2000). Specifically, experts typically create and use external representations (e.g., visualizations) from the mere beginning of the problem-solving process, which is supposed to help them to conceptualize the problem (Zou, 2000).

Particularly useful external representations that can potentially facilitate problem solving in mechanics are the free-body diagrams. According to Rosengrant, van Heuvelen, and Etkina (2009) free-body diagrams are "*diagrammatic representations in which one focuses only on an object of interest and on the forces exerted on it by other objects*." Free-body diagrams summarize the most important information about the physical situation described in a mechanics problem, which potentially facilitates conceptualization of the problem. As a matter of fact, Larkin and Simon (1987) believe that the main advantage of diagrams, compared to textual representations, is reflected in grouping together the most relevant information needed for problem solving, at a single location. This improves the clarity of the presented information and makes relevant information easier to notice. On the other hand, the fact that diagrams tell more than "thousands of words", can also lead to cognitive overload if students are expected to interpret the diagrams completely on their own, i.e., without instructor's guidance. As a matter of fact, unlike textual representations that communicate information in a linear, sequential way, diagrammatic representations are characterized by the intrinsic feature of communicating information holistically (Girwidz, 2015), which makes the students more dependent upon the instructor's guidance. Thereby, the level of needed guidance increases with increasing complexity of the diagrams. For example, it has been emphasized that using free-body diagrams that show components of relevant forces potentially results with confusion in students, as well as with the misconception that a real force and its components act on a body independent from each other (van den Berg & van Huis, 1998; Aviani, Erceg, & Mešić, 2015). Furthermore, if free-body diagrams are provided by the teacher, the students have to interpret them successfully first, before using them with the purpose of solving problems. In other words, students have to assimilate these representations in order to be in position to use them successfully for purposes of creating target knowledge structures, i.e., in order to solve the given problem. On the other hand, if the free-body diagram is not explicitly provided by the teacher, the students are expected to create the diagram on their own, before using it with the purpose of problem solving. Compared to the situation in which the diagram is provided by the teacher, students now do not get from the teacher summarized information about the problem in a visual form. However, in this situation a mitigating factor could be that students are basing their problem-solving process on self-constructed knowledge (i.e., self-constructed representations) rather than on interpretations of some „pre-fabricated" representations. In other words, the coupled system of internal and external representations in which information processing is supposed to occur is now more internally coherent. In addition, the mere process of externalizing representations allows the students to more effectively develop and test their own ideas (Reisberg, 1987). As a matter of fact, "*actively building external representations might promote organization and integration processes that foster the development of mental models*" (Wetzels, Kester, & Merrienboer, 2010, p. 229) which increases the level of beneficial, germane load.

In our study, two groups of students were expected to solve two versions of a five-problem assessment instrument. Thereby, one group of students has been provided with relevant free-body diagrams, whereby students from the other group were expected to figure out problem solutions completely on their own.

In earlier studies, it has been generally shown that the inclusion of "graphics" into problem statements decreases the difficulty of physics problems, whereas the need for interpreting symbolic drawings and the need for overcoming common misconceptions increases the difficulty of physics problems (Draxler, 2006). The decrease of problem difficulty could be theoretically explained by the dual (verbal and visual) coding of information that is relevant for the corresponding problem situation. On the other hand, it is also theoretically meaningful to hypothesize that for the students it is easier to use self-constructed than "pre-fabricated" representations, because they are more consistent with their internal representations. Eventually, we can conclude that, from a theoretical standpoint, the inclusion of free-body diagrams into the problems statements could result with increase, but also with decrease of problem difficulty.

In an attempt to contribute towards the resolution of the described theoretical dilemma, we decided to empirically investigate how the inclusion of free-body diagrams into statements of mechanics' problems influences first year physics students' performance on these problems.

Our hypothesis was of bi-directional nature, whereby we expected that inclusion of free-body diagrams into statements of mechanics' problems will significantly influence the problem difficulty.

The significance of our study is related to providing a counterintuitive but illustrative example of the relationship between externally provided and self-constructed representations within the context of problem solving in mechanics.

METHODOLOGY

Participants and relevant characteristics of the curriculum

For our study the target population consists of first year university students enrolled in introductory physics courses. The student sample for our study has been obtained by convenience sampling (Johnson & Christensen, 2012). Concretely, in our study we attempted to include all 66 students who were enrolled (in the academic year 2015/2016) in the Mechanics course, which is offered in the first year of study at the Physics Department of Faculty of Science Sarajevo. These 66 students have been randomly assigned to two groups, whereby the random allocation software by Saghei (n.d.) has been used. For these two groups of students we prepared two sets of problems that only mutually differed with respect to the inclusion of relevant free-body diagrams into the problem statement. The problem sets included five mechanics situations typically studied in introductory physics courses (see Appendix). Further evidence for validity of these problem sets has been obtained by inspection of the correlation between students' achievement on these problems and their achievement on the Mechanics exam (Pearson's $r=0.84$, $p<0.001$) that had been conducted one week before our experiment. When it comes to the design of the assessment instrument, it should be also noted that we used the same approach to drawing FBDs that had been used throughout the semester by the teaching staff of the Mechanics course.

Our experiment consisted of administering the two problem sets to two groups of students, whereby, unlike the control group, the experimental group has been provided with relevant free-body diagrams (i.e., FBDs were included in problem statements). The experiment has been conducted in the context of classroom hours reserved for recitations (i.e., problem solving exercises). Taking into account that the experiment was part of regular classes, we expected all 66 students to participate in the experiment. However, it should be noted that many of the 66 students from the official enrollment list much earlier dropped out from faculty which means that even weeks before our experiment the sample of students who regularly attended Mechanics classes amounted approximately to 50. Eventually, the recitation classes that we reserved for conducting our experiment were attended by only 36 students which is our final sample size for this study. According to Gall, Gall, & Borg (2003) for experimental research the sample size per group should not be below 15. In our study, each of the two groups consisted of 18 participants. The experimental group consisted of 5 males and 13 females and the control group consisted of 4 males and 14 females. Students from both groups were given two class hours (90 minutes) to solve the given problems, whereby it should be noted that most students from both groups finished solving the problems in 60 minutes.

For purposes of evaluating student achievement on the given problem set, we developed a scoring rubric which took into account the students' ability to write the expressions for relevant forces, as well as their ability to set up and solve the relevant equations (by applying Newton's laws). On each of the five problems a maximum score of 20 points could be obtained which means that, theoretically, the scale for the given problem sets ranged from 0 to 100 points. All papers have been marked by the same examiner, i.e. by the second author of this manuscript.

At the pre-university level, all our participants have been taught about kinematics and Newton's laws in eighth grade of primary school and then again (at a more quantitative level) in first grade of secondary school (year 10). Before the implementation of our experiment, the participants also have been taught about these topics within the context of the Mechanics course. The Mechanics course includes 3+3 class hours (per week) of lectures and recitations (problems solving exercises). Our experiment took place approximately two months after the beginning of the semester, and one week after the students wrote their first Mechanics exam.

Whereas traditional physics instruction at the pre-university level in Bosnia and Herzegovina, in general, is not characterized by systematic use of free-body diagrams, it should be noted that within the context of the Mechanics course students were required by the instructor (and teaching assistant) to systematically create and use free-body diagrams for purposes of problem solving, throughout the semester. Generally, the contents that are taught in Mechanics are very similar to the contents that are taught in typical introductory courses of physics. However, the level of calculus use is very low. In the Mechanics course, students were not only expected to learn the most important facts, but also to show deep conceptual understanding of the subject and ability to solve typical introductory mechanics problems. Generally, the effectiveness of the Mechanics course could be described as above average.

Research design

In order to check our hypothesis, it was necessary to investigate the performance of two equivalent groups of students on two sets of mechanics' problems that only mutually differed to the point that one of the two sets also contained free-body diagrams in the problem statements. As emphasized earlier, the two groups of students were obtained by means of random assignment. Taking into account the fact that the reliability of random assignment is dependent on the sample size (which is relatively small for our study), the pre-experimental equivalence of the groups has been additionally checked by analyzing between-group differences on the Mechanics exam that had been conducted one week before our experiment. The pre-experimental differences (1.2 points in favor of control group, on a scale from 0 to 25), as measured by the Mechanics exam, proved to be non-significant, $F(1, 34) = 0.24$ ($p=0.63$).

RESULTS

After the score for each participant on each item had been determined, an overall score for each participant on the given five-problem set could be calculated. Table 1 contains information about between-group differences in average scores, for the given five-problem set (see Appendix).

Table 1. *Analysis of between-group differences for the given five-problem set. Theoretically, the scale ranges from 0 to 100.*

Groups	N	Mean score	Standard deviation
FBD – not provided	18	73.5	25.3
FBD - provided	18	47.4	31.4

From Table 1 we can see that, on average, students from the control group (FBD not provided in the problem statement) scored 26.1 points higher than students from the experimental group (FBD provided in the problem statement).

Furthermore, we decided to check whether the observed effect is statistically significant, whereby we also took into account the potential pre-experimental differences as measured by students' achievement on the Mechanics exam. Such a statistical check could be accomplished by performing an analysis of covariance (ANCOVA) with student achievement on the

Mechanics exam as a covariate. It could be shown that for our data the assumptions of homogeneity of variance, homogeneity of regression slopes and independence between covariate and treatment effect were met. However, for the control group the distribution of test scores proved to significantly depart from normality. Although, ANCOVA is considered to be pretty robust to violations of the normality assumption (Rutherford, 2011), we decided to accompany the regular ANCOVA with a bootstrap for parameter estimates. According to Field (2013) if we bootstrap parameter estimates we can have confidence in these being robust.

The results of regular ANCOVA show that that there is a significant effect of inclusion of FBDs into problem statements on students' score on the five-problem set, $F(1, 33) = 25.92$, $p<0.001$. By using the relationship between F and t, as well as between t and r (see Rosnow, Rosenthal, & Rubin, 2000), we can show that the relationship between group membership (no FBDs vs FBDs) and problem solving performance is characterized by $r=0.66$ which can be considered as a large effect.

From Table 2 we can conclude that even after adjusting for Mechanics exam score, the between-group difference on the given problem set amounts to 21.91 points (on a scale that ranges from 0 to 100). Based on the bootstrapped significance and confidence intervals, we could conclude that the group not provided with FBDs significantly outperformed the group that was provided with FBDs in the problem statements, $p<0.001$.

***Table 2**. ANCOVA - bootstrap for parameter estimates*

Parameter	B	Bootstrap*				
		Bias	Std. Error	Sig. (2-tailed)	BCa 95% Confidence Interval	
					Lower	Upper
Intercept	15.23	-0.15	3.71	0.000	8.24	21.80
Mechanics exam score	3.47	0.02	0.30	0.000	2.95	4.08
Group (no FBD vs FBD)	21.91	0.16	4.19	0.000	13.20	31.16

**Bootstrap results are based on 10 000 bootstrap samples.*

Furthermore, we were interested to check whether the observed effect was present for all problems, or only for some of the problems (see Table 3).

***Table 3.** Analysis of between-group differences on individual problems; mean score and standard deviation for each individual problem is provided. Theoretically, for individual problems the scale ranges from 0 to 20.*

Groups	Problems	N	Mean score	Standard deviation
FBD – not provided	Problem 1	18	15.2	7.2
	Problem 2	18	13.2	8.8
	Problem 3	18	16.5	6.2
	Problem 4	18	15.8	7.7
	Problem 5	18	12.7	5.3

FBD - provided	Problem 1	18	9.4	6.9
	Problem 2	18	9.8	8.4
	Problem 3	18	9.3	8.4
	Problem 4	18	10.4	10.0
	Problem 5	18	8.6	7.0

From Table 3 we can see that largest between-group differences have been obtained for Problem 3 and Problem 1. It is interesting to note that only in these two problems, the provided FBDs showed resolution of some relevant forces into multiple components. Furthermore, it was found that only for these two problems the between-group differences were statistically significant (for Problem 1: $t\ (34) = 2.46$, $p=0.019$; for Problem 3: $t\ (31.3) = 2.94$, $p=0.006$). These differences are statistically significant even after accounting for multiple comparisons by using Benjamin-Hochberg procedure and setting a false discovery rate of 0.05 (McDonald, 2014).

Finally, we decided to inspect more closely whether or not the students from the control group (i.e., group in which students were not provided with FBDs in the problem statement) attempted to create free-body diagrams on their own. Thereby, it has been shown that even 13 out of 18 students from the control group created free-body diagrams for all five problems. The average number of problems for which students from control group attempted to create free-body diagrams was 4.2 out of 5. Correlational analyses showed that there was a statistically significant correlation between number of problems for which free-body diagrams have been created and score on the five-problem set ($r=0.7$, $p=0.001$), as well as between number of problems for which free-body diagrams have been created and achievement on the Mechanics exam that had been conducted one week earlier ($r=0.72$, $p=0.001$).

DISCUSSION

Taking into account the fact that the pre-experimental differences as measured by the Mechanics exam proved to be non-significant, as well as the fact that our samples had been obtained by random assignment, we can conclude that inclusion of free-body diagrams into the problem statements significantly influenced the rate of students' success on the given problem set. Concretely, it has been found that inclusion of FBDs into problem statements could even impede problem solving in mechanics for student samples characterized by a relatively good background in mechanics' knowledge. The effect was particularly pronounced for problems that required from experimental group students to interpret free-body diagrams showing resolution of forces into components.

The first impression is that the obtained results seem to be counterintuitive: providing the students with summarized conceptual information about most important features of the given problem situation (via free-body diagrams), sometimes not only does not facilitate problem solving, but impedes it. In other words, our results support the argument that evaluating can be more difficult than creating. More precisely, sometimes for the students it is easier to solve a physics problem by relying on self-constructed representations, than to rely on representations provided by the teacher. One could attempt to explain this result by resorting to basic ideas of cognitive load theory (Sweller, van Merrienboer, & Paas, 1998; Paas, Renkl, & Sweller, 2003). In that sense, it could be asserted that the interpretation of the externally provided (already completed) free-body diagram is consuming more memory resources than the step-by-step construction of the same diagram by the student.

The cognitive load is especially prominent for diagrams that include resolutions of forces into components, i.e. for more complex diagrams. For these diagrams the intrinsic load is relatively high due to the fact that these diagrams contain relatively *many*, *different* entities. In addition, there is also a relatively high level of extraneous load due to the fact that students from the experimental group were required to interpret the teachers' intentions related to the meaning of different parts of FBDs, including their aesthetic aspects such as different colors and shapes of the arrows. Consequently, there were not many memory resources left for germane load, i.e., for relevant knowledge construction.

As a matter of fact, multiple researchers have already advocated against using free-body diagrams that include resolution of forces into components (Kondratyev & Sperry, 1994; Aviani, Erceg, & Mešić, 2015). They point out that showing components can cause confusion and/or cognitive load in students. Also, there is danger that students come to believe that components act on a body independent of the corresponding real force (Aviani, Erceg, & Mešić, 2015).

It should be noted that our example shows that self-construction of free-body diagrams can be more productive than interpretation of (externally provided) free-body diagrams only for the context when the students are presented with *already completed* FBDs, without further guidance being provided by the teacher. This, once more, illustrates how important it is to demonstrate the *process* of construction of FBDs on the blackboard, instead of only presenting the students with already completed FBDs via electronic presentations. The step-by-step construction implies that only a low number of chunks of knowledge is processed at one time, and it ensures the sequential integration of these individual chunks over time. Thereby, in self-regulated learning, the student switches to the next chunk (e.g., next part of the FBD) only after she/he feels that the first chunk has been processed adequately. On the other hand, learning that is based on externally provided (already completed) FBDs can be sometimes ineffective because, unlike textual representations that communicate ideas in a sequential form, diagrams provide information in a holistic form (Girwidz, 2015) which requires from the learner a higher level of metacognitive thinking. Whereas the students from the experimental group tried to conceptualize the problem based on the *externally provided* (already completed) free-body diagram, the students from the control group achieved conceptualization within the mere *process* of the step-by-step construction of the free-body diagram. Taking into account that cognitive processing occurs in the coupled system of internal and external cognitive representations (Nersessian, 2008), it should be noted that for the students from the control group the (self-constructed) external representations certainly were more consistent (and easier to interpret) with their internal representations than it was the case for students from the experimental group who relied on externally provided representations. In addition, the mere process of externalizing representations assisted students' reasoning by directing them to develop and examine their own ideas (Cox, 1999).

SUMMARY AND CONCLUSION

In this study, we investigated how inclusion of free-body diagrams into problem statements influences first year physics students' performance in solving mechanics problems. To that end, we created two versions of a five-problem assessment instrument that only differed with respect to the inclusion/non-inclusion of free-body diagrams within the problem statements. These two versions of the assessment instrument were administered to two groups of first year physics students that had been obtained by the procedure of random allocation. It has been shown that inclusion of free-body diagrams into the problem statement not only did not facilitate problem solving, but even impeded it significantly. Particularly large between group differences, in favor of the control group (no FBDs in the problem statements), were detected for problems that required use of free-body diagrams showing resolution of forces into components. Within the control group the number of problems for which students constructed free-body diagrams strongly and positively correlated with students' problem solving performance, as well as with the student achievement on the Mechanics exam that had been conducted one week earlier.

Our conclusions are as follows:

- Our results support the idea that problem solving is facilitated if students are expected to externalize representations of knowledge on their own (see Reisberg, 1987).
- Sometimes for the students it is easier to effectively use self-constructed representations than to use externally provided representations. This is in line with the similar idea that self-generated analogies are sometimes more productive than analogies provided by the teacher (Wong, 1993) and with the idea of self-regulated learning, in general (Woolfolk, 2013).
- Cognitive processing occurs within the coupled system of internal and external representations of knowledge (see Nersessian, 2008), whereby the effectiveness of information processing largely depends on the coherence between internal and external representations. A high degree of coherence can be established when external representations (and representations, in general) are self-constructed by the students.
- Our results are in line with the idea that the decomposition of forces approach to drawing and using free-body diagrams can result in cognitive overload and confusion (Kondratyev & Sperry, 1994, van den Berg & van Huis, 1998; Aviani, Erceg, & Mešić, 2015), especially in situations when students are presented with already completed diagrams.
- Our results support the idea that (self-)construction of free-body diagrams strongly and positively correlates with mechanics' problem solving, and achievement in typical introductory mechanics' courses (see Rosengrant, van Heuvelen, & Etkina, 2009).

Our suggestions for the teaching practice are as follows:

- Physics teachers should provide their students with more opportunities for self-regulated learning. If thereby students are expected to use some representations prepared by the teacher, the teacher should attempt to ensure a low as possible level of extraneous load (e.g., by explicitly emphasizing her/his intentions related to the design of various aspects of the representation). At the same time the teacher should be cautious not to constrain too much students' individual learning pathways.
- Physics teachers should insist on systematic construction and use of free-body diagrams in introductory mechanics' courses (at the university level, as well as at lower educational levels).
- Presentation of already completed diagrams in physics instruction should be avoided – it is very important to demonstrate the mere *process* of the creation of the diagram. Generally, we must be careful to accompany the use of diagrams in physics instruction with a higher level of teacher guidance (Girwidz, 2015).

A limitation of this study is related to the fact that it is based on a relatively small sample size. In addition, conclusions are based only on a sample of five typical problems, which means that our study cannot provide conclusions about possible differential effects related to various subtypes of mechanics' problems. Further, it is very important to note that the conclusions of our study are delimited to university students with a good background in mechanics who are already accustomed to draw and use FBDs on their own (13 out of 18 students from the control group drew diagrams for all 5 problems). For students who are not well versed in drawing and using diagrams on their own it would not be reasonable to expect that provision of pre-fabricated FBDs impedes problem solving. Generally, it is important to note that the effectiveness of reasoning with external representations largely depends on student's prior foreknowledge (see Cox, 1999).

Consequently, we will attempt to base our next study on a larger and more diverse sample of participants as well as on a more diverse set of problems. It would be also interesting to check whether the between-group difference on problems 1 and 3 would stay the same if we provided the experimental group students with FBDs showing only real forces (see Aviani, Erceg, & Mešić, 2015) instead with FBDs that show decomposition of forces. Finally, it would be interesting to check whether the effect of inclusion of FBDs into the problem statement depends on some cognitive features of the students (e.g., metacognitive ability).

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APPENDIX

We provide below the five-problem assessment instrument that had been solved by students from the experimental group. The assessment instrument for the control group was nearly the same – it only differed to the point that it did not include free-body diagrams within problem statements.

Problem set – Experimental group **Name of the student:**

Problem 1

A block of mass *m*=2 kg is pushed across a surface with a force *F*= 40 N that acts on the block at an angle *θ*=30° with the horizontal (see Figure 1).

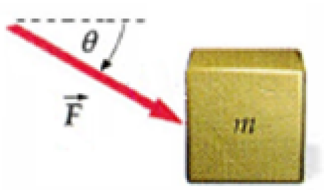

Fig. 1. Illustration of Problem 1

Find the acceleration of the block provided that the coefficient of friction between the block and the surface is 0.1. Please find below the free-body diagram for the given block (see Figure 2).

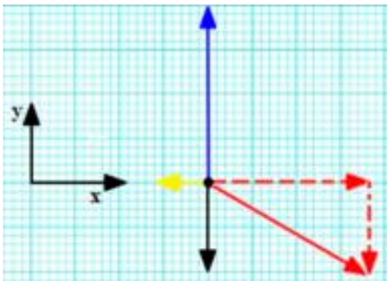

Fig. 2. Free-body diagram for Problem 1

Problem 2

The Figure 3 shows two blocks of mass m_1=4 kg and m_2=2 kg that are connected by a massless, inextensible rope. The rope passes over an ideal (frictionless and massless) pulley.

Fig. 3. Illustration of Problem 2

Find the tensions in the string that are acting on the two blocks of mass m_1 and m_2. Please find below the free-body diagrams for the given blocks (see Figure 4).

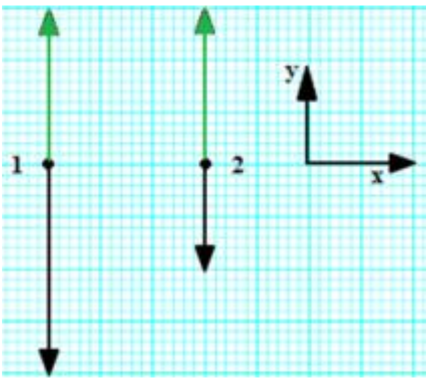

Fig. 4. Free-body diagrams for Problem 2

Problem 3

Block of mass m=12 kg slides down the incline with constant velocity (see Figure 5).

Fig. 5. Illustration of Problem 3

What is the magnitude of the frictional force between the block and the incline? The angle of the incline is θ=30 °. Please find below the free-body diagram for the given block (see Figure 6).

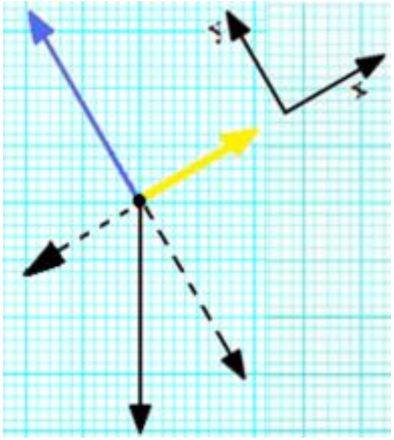

Fig. 6. Free-body diagram for Problem 3

Problem 4

Force *F* is pushing the block of mass *m*=1 kg against the wall so that the block remains at rest (see Figure 7).

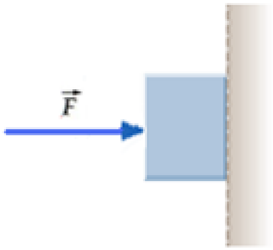

Fig. 7. Illustration of Problem 4

Find the minimal magnitude of force *F* that needs to act on the given block so that it remains at rest. Coefficient of friction between the block and the wall is 0.4. Please find below the free-body diagram for the given block (see Figure 8).

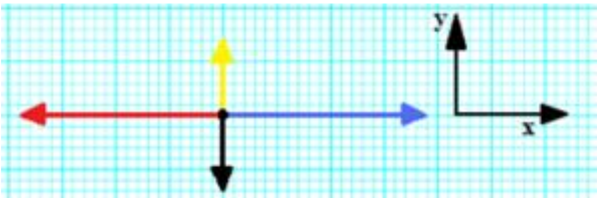

Fig. 8. Free-body diagram for Problem 4

Problem 5

Find the acceleration of the system showed in Figure 9, as well as the magnitude of tensions in the ropes. The coefficient of friction between block of mass m_2 and the horizontal surface is μ=0.2. The pulley can be considered as frictionless and air resistance can be neglected.

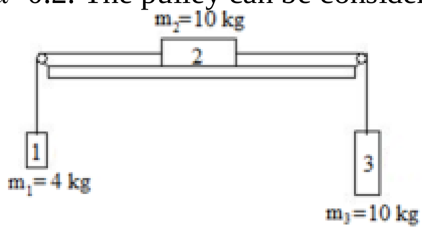

Fig. 9. Illustration of Problem 5

Please find below the free-body diagrams for the given blocks (see Figure 10).

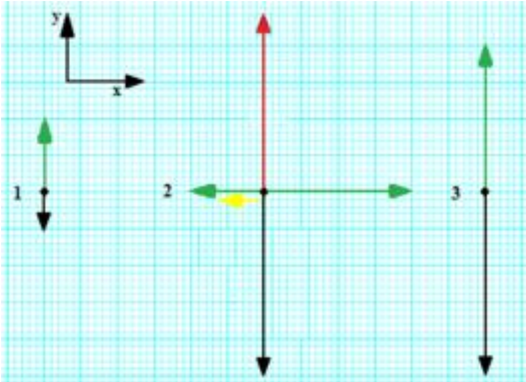

Fig. 10. Free-body diagrams for Problem 5