Ensaio • Pesquisa em Educação em Ciências. 2019; 21:e10545
DOI: http://dx.doi.org/10.1590/1983-21172019210110

ARTICLE

STUDENTS' ENGAGEMENT ON A SCHOOL INVESTIGATION ABOUT SIMPLE ELECTRIC CIRCUITS

ALEXANDRE F. FARIA [I *]
https://orcid.org/0000-0002-5629-0612

ARNALDO M. VAZ [II **]
https://orcid.org/0000-0002-5676-1699

[*] Doctor in Education/Universidade Federal de Minas Gerais (UFMG). Physics Teacher at Colégio Técnico, UFMG.
E-mail: < affaria@ufmg.br >.

[**] PhD in Education/Surrey University. Physics Teacher at Colégio Técnico and Postgraduate Program in Education Professor, UFMG.
E-mail: < arnaldovaz@ufmg.br >.

ABSTRACT: Laboratory in Physics teaching can serve many pedagogical objectives. One of the proposals to physics labs involves the use of investigative activities. In this paper, we present the results of a study about high school students' engagement in an investigative activity about electrical circuits. The aim of this study was to characterize the engagement of these students in this activity. The research was conducted in a Brazilian federal high school located in Belo Horizonte/Minas Gerais. We recorded groups of three to four year students during physics lab lessons. The data analysis was based on the concept of engagement and its indicators established in research literature. The results reveal that all students exhibited involvement in the activity but not all engaged in tasks proposed in it. Among the students who engaged in tasks, we identified variations in the quality of their involvement.
Keywords: Engagement; Investigative Activities; Physics Teaching.

ENGAJAMENTO DE ESTUDANTES EM INVESTIGAÇÃO ESCOLAR SOBRE CIRCUITOS ELÉTRICOS SIMPLES

RESUMO: Buscam-se objetivos variados com as atividades desenvolvidas no laboratório escolar de Física. Entre as várias propostas para esse ambiente de aprendizagem estão aquelas que o concebem a partir de atividades investigativas, com diferentes níveis de abertura. Neste trabalho, apresentamos os resultados de uma investigação sobre o engajamento de estudantes do Ensino Médio durante o desenvolvimento de uma atividade investigativa semiaberta sobre circuitos elétricos simples. O objetivo do

[I] Universidade Federal de Minas Gerais, Belo Horizonte, MG - Brasil.

[II] Universidade Federal de Minas Gerais, Programa de Pós-Graduação em Educação: Conhecimento e Inclusão Social, Belo Horizonte, MG - Brasil.

trabalho foi caracterizar o engajamento desses estudantes nessa atividade. O estudo foi conduzido numa escola pública brasileira, vinculada à Rede Federal de Educação Profissional, Científica e Tecnológica, localizada na cidade de Belo Horizonte/MG (Brasil). A coleta de dados envolveu gravações de áudio e vídeo de grupos de três a quatro estudantes no laboratório de física da 1ª série do Ensino Médio. A análise dos dados baseou-se no conceito e nos indicadores de engajamento estabelecidos na literatura de pesquisa. Os resultados mostram que embora todos os grupos tenham demonstrado algum envolvimento com a atividade, nem todos os estudantes se engajaram na resolução das tarefas propostas. Entre os que se engajaram nas tarefas, percebe-se variação na qualidade desse envolvimento.
Palavras-chave: Engajamento: Atividades Investigativas; Ensino de Física.

COMPROMISO DE ESTUDIANTES CON UNA INVESTIGACIÓN ESCOLAR SOBRE CIRCUITOS ELÉCTRICOS SIMPLES

RESUMEN: Se buscan objetivos variados con las actividades desarrolladas en el laboratorio escolar de Física. Entre las varias propuestas para ese ambiente de aprendizaje se hallan aquellas que lo comprenden a partir de actividades investigativas, con distintos niveles de apertura. En este trabajo, presentamos los resultados de una investigación sobre el compromiso de estudiantes de Enseñanza Media a lo largo del desarrollo de una actividad investigativa semiabierta sobre circuitos eléctricos simples. El objetivo del trabajo fue caracterizar el compromiso de esos estudiantes con esa actividad. El estudio fue dirigido en una escuela pública brasileña, vinculada a la Red Federal de Educación Profesional, Científica y Tecnológica, y ubicada en la ciudad de Belo Horizonte/Minas Gerais (Brasil). La recopilación de datos ocurrió por medio de grabaciones de audio y videos de grupos de tres a cuatro estudiantes en el laboratorio de Física del 1º año de la Enseñanza Media. El análisis de datos se basó en el concepto y en los indicadores de compromiso establecidos en la bibliografía de investigación. Los resultados señalan que, aunque todos los grupos hayan demostrado cierta participación, no todos los estudiantes se comprometieron con la resolución de las tareas propuestas. Entre los que se comprometieron con las tareas, se percibe una variación en la calidad de ese compromiso.
Palabras clave: Compromiso; Actividades Investigativas; Enseñanza de Física.

INTRODUCTION

For decades, a debate has been going on about the underpinnings, the purposes and the potentiality of the school laboratory and of other practical activities in Science Education (BAROLLI; LABURÚ; GURIDI, 2010; BORGES, 2002; GOMES; BORGES; JUSTI, 2008; HODSON, 1988; HOFSTEIN; LUNETTA, 1982; HOFSTEIN; LUNETTA, 2004; WHITE, 1996; WILCOX; LEWANDOWSKI, 2017). The conduction of practical activities, within and without the laboratory, has been described and analyzed from different conceptual and theoretical perspectives (JULIO; VAZ, 2007; KIPNIS; HOFSTEIN, 2008; REIGOSA; ALEIXANDRE, 2011; SANDI-URENA et al., 2011; WOLF; FRASER, 2008).

In such discussions, there are authors that suggest to structure the school laboratory around investigative activities (BORGES, 2002; HOFSTEIN; LUNETTA, 2004; KUHN et al., 2017; TAMIR; STAVY; RATNER, 1998; ZÔMPERO; LABURÚ, 2011). The concept of school investigation is multifaceted (BARROW, 2006; MUNFORD; LIMA, 2007; RODRIGUES; BORGES, 2008; ZÔMPERO; LABURÚ, 2011). For this reason, we make clear from start that we base our comprehension of investigative activities on the work of Borges (2002). Investigative activities involve challenges or problems with varying degrees of openness, which might either demand conducting experiments, computer simulations or video analysis, or simply using pencil and paper. The most open challenges or problems are those which do not present immediate solutions and require reflection on the part of the students. These require greater autonomy of them.

Some research suggests that investigative activities have the potential to stimulate the use of reasoning and learning strategies, to promote the functional understanding of concepts, and promote student collaboration and engagement (JULIO; VAZ; FAGUNDES, 2011; KANARI; MILLAR, 2004; KASSEBOEHMER; FERREIRA, 2013; KIPNIS; HOFSTEIN, 2008; KUHN et al., 2017; WILCOX; LEWANDOWSKI, 2017; WOLF; FRASER, 2008). On the other hand, there are reaserches with results that surprise by their counter-intuitive character, therefore, should be carefully observed. For instance, Kirschner, Sweller e Clark (2006) conclude, based on literature review work, that open investigative school activities do not promote learning gains compared to structured teaching activities. In some cases, the open ones would be even less efficient. This conclusion shows the importance of adjusting the degree of openness of an investigative teaching activity to the audience for which it is intended (Cf. BORGES, 2002; MUNFORD; LIMA, 2007). As surprising as these are the results of Barron (2000, 2003) or of Julio, Vaz and Fagundes (2011) that reveal difficulties presented by students regarding the engagement in the process of solving the tasks of investigative activities. These results are important because they indicate that student engagement may not occur even in activities with favorable characteristics or may occur with loss of focus on the proposed tasks.

These research results have inspired us to propose that the concept of engagement has the potential to contribute to researching the experiences of students involved in investigative school activities. This potential lies in the possibility of characterizing the involvement of students in the processes of problem solving and in the tasks that make up investigative activities, as well as in the possibility of identifying elements that favor or restrict that involvement. Our proposal meets a common demand for teaching and research: the need for instruments to evaluate teaching and learning processes in open activities.

That said, we present in this article the results of an investigation about the engagement of tenth grade students (aged 14 to 15) in a Brazilian public school. Our objective was to characterize students' engagement in an investigative school activity on simple electrical circuits.

SCHOOL ENGAGEMENT

The concept of School Engagement – or simply engagement – refers to the relation that the student establishes with the school activities that are proposed to her or to him. This relationship is influenced by the students' interaction with the context. Engagement is said to be malleable because changes in such context can alter the relationship that students establish with activities (FREDRICKS; BLUMENFELD; PARIS, 2004; FRYDENBERG; AINLEY; RUSSELL, 2005; OGAN-BEKIROGLU; ESKIN, 2012; OLITSKY; MILNE, 2012; SHERNOFF et al., 2015).

According to Fredricks, Blumenfeld and Paris (2004), engagement has three dimensions: behavioral, emotional and cognitive. Behavioral engagement relates to the participation and involvement of students, as well as to the positive behaviors undertaken by them. Emotional engagement involves the affective and emotional reactions of students to an activity, subjects, and other elements that make up the school environment. Cognitive engagement relates to student investment in learning. It is marked by the effort undertaken to reach higher levels of understanding on a given subject.

Olitsky and Milne (2012) consider that this definition of engagement is flawed, disregarding the complex relationship between the behavioral, emotional and cognitive dimensions. In our view, the critique presented by Olitsky and Milne is not directed towards the definition of engagement itself, but to research methodologies - such as the use of questionnaires - considered inadequate to deal with the complexity of teaching-learning. For us, the multidimensional conception of engagement allows us to deal with this complexity by employing methodological strategies such as observation and recording of students in regular class activities. The dimensions of engagement may be useful points of view. If used as lenses, the effects of teaching and of students' learning processes can be seen from different perspectives.

In addition to its malleability, engagement has also attracted the attention of managers, researchers and teachers for another reason: its correlation with students' school performance. This allows us to infer that engaged students take better advantage of the learning opportunities offered to them (AINLEY, 1993; BORGES; JULIO; COELHO, 2005; CHRISTENSON; RESCHLY; WYLIE, 2012; FREDRICKS; BLUMENFELD; PARIS, 2004; FRYDENBERG; AINLEY; RUSSELL, 2005; MARKS, 2000; NEWMAN, 1992; SINGH; GRANVILLE; DIKA, 2002).

It should be noted that the concepts of engagement and motivation are usually treated as referring to the same thing. However, these are different concepts

(FRYDENBERG; AINLEY; RUSSELL, 2005; MARTIN; GINNS; PAPWORTH, 2017; NEWMANN; WEHLAGE; LAMBORN, 1992). For example, a student may be motivated to have a good performance overall without being engaged in specific school tasks.

Motivation is related to the psychological processes that exert influence on students' behavior in learning situations. It is related to the reasons or motives that lead a certain person to act in a certain way. Engagement, on the other hand, refers to the relationship that someone - who is in contact with a teacher, or with other well-defined person - establishes with a very specific activity; either in time or in the other circumstances or characteristics in which it occurs (FRYDENBERG; AINLEY; RUSSELL, 2005).

The studies in the field of Science Education research that investigated student engagement, did so in diverse school situations, with different purposes as well and with varied theoretical background (BORGES; JULIO; COELHO, 2005; JULIO; VAZ; FAGUNDES, 2011; MILNE; OTIENO, 2007; MOREIRA; PONTELO, 2009; OGAN-BEKIROGLU; ESKIN, 2012; SASSERON; DUSCHL, 2016). These studies can be classified into three groups: those that conceive engagement as a multidimensional construct in line with Fredricks, Blumenfeld and Paris (2004); those who dwell on the notion of "productive disciplinary engagement" of Engle and Conant (2002) and those who propose to investigate the engagement without defining it explicitly.

Julio, Vaz and Fagundes (2011), for example, observed the way students interacted in a sequence of classes in which there was an investigative activity of Physics in groups. Audio and video recordings were analyzed, based on the articulation of the psychoanalytic concepts of "work group" and "basic assumptions" with the multidimensional concept of engagement. The results indicate that students engaged in the activity as a whole may not be engaged in the various specific tasks proposed by the teacher.

Milne and Otieno (2007) investigated the engagement of students in Chemistry classes in which demonstrations about the law of gases were developed, in a dialogical way. These researchers analyzed video vignettes based on a multidimensional understanding of the concept of engagement liased with referents of the Sociology of emotions. The results indicate that students have engaged in demonstrative activities from the outset. These activities provided the initial support for student engagement, which allowed the teacher to reorganize her actions and strategies in the conduct of the activity and establish new opportunities for engagement and learning.

Borges, Julio e Coelho (2005) investigated the levels of behavioral and cognitive engagement of high school students in a learning environment from a curricular innovation proposition. They analyzed the influences of the learning environment on student engagement levels and the interrelationships between behavioral, cognitive engagement and learning. The indicators of engagement were based on notes obtained in tests composed of open questions and data on the performance in general activities such as reading texts, elaboration of summary and involvement in discussions with colleagues. The results indicate that the designed learning environment favored the maintenance of students' behavioral engagement throughout the year, but not of cognitive engagement. It was also realized that the maintenance of behavioral engagement does not imply learning. For it to occur, students must be cognitively engaged.

Moreira e Pontelo (2009) investigated the engagement of high school students in scientific initiation involved on a project about school laboratory based on computer assisted acquisition and treatment of data. The interviews with the students were analyzed based on the articulation between Activity Theory and the multidimensional concept of engagement. In this process, Moreira and Pontelo developed and used the constructs: operational engagement (level of actions and operations) and comprehensible engagement (level of activity). The results indicate that the different levels of student engagement can be partially explained by the differences in the relation between the initial meaning that the students attribute to the activities and their actual meaning.

Coelho (2011) used a set of statistical tools and analyzed data extracted from daily school activities to evaluate which factors influenced the evolution of the conceptual understanding of electricity. The author collected data from students in five high school technical courses at a federal school and concluded that, statistically, the factor that most contributed to the evolution of the conceptual understanding was cognitive engagement. The following are factors such as behavioral engagement and socioeconomic origin.

METHODOLOGICAL DESIGN

SCHOOL CONTEXT

The data analyzed in this study was collected at a federal public school in Belo Horizonte (Brazil) with a tradition of didactic activities in laboratories. Every week, students had three 50-minute classes in a conventional classroom and, every two weeks, another two 50-minute classes in the lab. We observed physics classes of two tenth grade classrooms during two academic quarters, in conventional classrooms and in the laboratory. However, data collection only occurred in laboratory classes.

In the laboratories, the class was divided into two sub-groups with 13 or 14 students each. While one of the sub-groups developed activities in the Physics lab, the other participated in another discipline. The order was reversed the following week. The students always worked in groups, which had a fixed constitution of three or four members.

ACTIVITY ANALYZED

We analyzed the 11th laboratory class of the year: an investigative activity where problems with varying degrees of openness were proposed (Cf. BORGES, 2002). It was a class on the second quarter with an organization similar to that of previous laboratories: a semi-structured script guided the work of the groups (see appendix).

The activity introduced electricity content knowledge and was regularly developed as part of the High School Physics program. We decided to analyze it because in the process of data collection and, later, while screening all the data, we observed the way that activity facilitated students' interactions while they performed its tasks. This was a key feature for investigating engagement from audio recordings of videos of students' groups.

Our analysis was inspired by the definition of episode given by Mortimer et al (2007): "[...] a coherent set of actions and meanings produced by the participants in interaction, which has a clear beginning and end and which can be easily discerned from previous and subsequent episodes." Careful observation of the class recordings allowed us to clearly distinguish three episodes:

• Episode 1 – Assembly of a Simple Circuit with an Electric Lamp: Students were asked to assemble simple circuits with only one lamp, wires and an electric battery. They should draw these three items in situations where the bulb is lit and also in those in which it is not lit. In addition, they should explain why some circuits worked and others did not.

• Episode 2 - Batteries of Different Sizes and Lamp Brightness: Students predicted, observed, and explained the brightness of a lamp when attached to batteries of different sizes, both 1.5 volts.

• Episode 3 – Assembly of simple circuits with two lamps: It was requested the assembly of circuits in series and parallel with two lamps. They should draw the circuits that worked and those that did not work. They should also predict, observe and explain what would happen to the brightness of the other light bulb in the circuit if one of them were burned out or switched off.

RESEARCH VOLUNTEERS

Twenty-two students from two high school classes - nine from one class and thirteen from another - took part in the study. Male and female participants were between the ages of 15 and 16 at the time, with the exception of an 18-year-old student. There were also two more volunteers: a teacher, doctor in Education, and a teacher, specialist in Science Teaching; both with several years of performance in Basic Education.

We were watchful of everyone's anonymity, so we associated fictitious names with classes, students and teachers. All volunteer students agreed, with their responsibles' consent, to contribute with the research by signing the Informed Consent Term.

DATA COLLECTION AND ANALYSIS STRATEGIES

We accompanied four groups of students (two per class). To film them, we positioned a camera at the back of the room in each class. We framed only groups with volunteers. We placed audio recorders on their workbench, which ensured good quality recordings of their verbal interactions. During filming, one of us remained in the room and used a field diary to take notes of events that caught the eye and seemed relevant to the research goals.

At the first contact with the data, we watch the recordings continuously, without any interruption in playback. We observe how the students relate to the proposed activity; their organization during the process of solving the problems that compose the activity; the students' discussions with each other; and the discussions of the students intermediated by the teacher. We identify portions of the recordings with indications of student engagement in task resolution. With each annotation, we took note of the corresponding recording time.

On the second and third time we watch the videos, we make sure that the notes are consistent and include new notes about events that have previously gone unnoticed. When necessary, we pause, advance or rewind the video.

Based on these notes, we highlight sections of the class with the presence of indicators of student engagement in the activity. We counter the information obtained through this means with the notes made in the field diary. In case of doubt or divergence we return to watch the videos. With these indicators located, we transcribe and analyze the utterances or speech sequences of the corresponding video clips.

To identify each transcribed utterance, we use E1.3 notation where "E1" designates that the utterance was extracted from episode 1 and "3" indicates the order of the utterance in the transcribed sequence.

ENGAGEMENT INDICATORS

There is research on students' engagement in school activities based on direct observation of the classroom or on audio and video recordings (Cf. COELHO, 2011; FREDRICKS; BLUMENFELD; PARIS, 2004; JULIO; VAZ; FAGUNDES, 2011; OLITSKY; MILNE, 2012). These observational techniques contribute to the analysis of the behavioral, emotional and cognitive factors of learning and thus avoid the fragmentation highlighted by Olitsky and Milne (2012). The classroom observation gives indications of the engagement that emerges from the interactions between the students, theirs with the teacher, and from them with the other material and immaterial elements that constitute the context of the activity. However, this is not a predominant approach, and the use of questionnaires and interviews with students is more common.

We investigate students' engagement by direct observation and audio and video recordings of class. Annotations we made during class and recordings were used to identify indicators of student engagement. Our indicators are based on Fredricks, Blumenfeld e Paris (2004) and on Sinatra, Heddy and Lombardi (2015). They are presented in Box 1.

Box 1. Engagement indicators.

Behavioral	Emotional	Cognitivo
Observation and adherence of students to the norms and agreements established in the group and in the class as a whole; Respect for the opinions, suggestions and ideas of colleagues; Involvement in the resolution of tasks; Effort, persistence and concentration in the resolution of tasks; Individual contributions to task resolution; Collaboration for task resolution.	Joy, well-being, happiness, excitement, pride, pleasure and satisfaction; Anxiety, frustration, nervousness, agitation, nonconformity and boredom.	Use of learning strategies such as writing annotations and summaries in the notebook; Cognitive investment in the understanding of task-focused phenomena; Cognitive investment in the understanding of relationships, concepts and ideas related to the tasks; Effort to deepen or perfect what is already known; Effort to appropriate general domain strategies; Flexibility in task resolution.

RESULTS AND DISCUSSION

GROUP G1: CARLOS, MANOEL E MIRELA

The three students were curious, participative and liked to show that they dominated the content of Physics. There was some rivalry between them, but that did not stop them from treating each other with respect and working for the group. Mirela had a good relationship with the two boys. She demonstrated insecurity in different situations, which did not compromise her participation. This student was responsible for solving many impasses and for maintaining harmony in the group.

The behavioral engagement of G1 members can be characterized by collaboration and great interest and involvement in the process of solving the task. They all manipulated the available materials and participated in the assembly of the circuits, even if occasionally they had to squirm and to put themselves over the others on the workbench to gain access to the materials. They persisted in the unsuccessful attempts to assemble the circuits, although this caused discomfort, especially among the boys. The ideas and proposals for solving the tasks that emerged in the group were welcomed and discussed. Emotional engagement in G1 was evidenced by the excitement with which they dealt with the tasks proposed and the satisfaction they demonstrated at the moments when they succeeded in making the electrical circuits work (at times, they came to vibrate as sports fans).

The performance of the G1 students to solve the tasks of the activity on electric circuits gave us indications that they also engaged cognitively, especially in the second episode of the lesson: where they should predict, observe and explain what happens to the brightness of a lamp connected to batteries of different sizes. The counterintuitive character of the second episode's task seems to have particularly mobilized these students:

E2.1. Teacher A: But what were you waiting for?

E2.2. Carlos: That it increased.

E2.3. Teacher: Why?

E2.4. Carlos: Uh, because it's a bigger number ... Greater power. A greater intensity. We don't say "intensity", do we? It's more volts.

E2.5. Manoel: It is not, no. It is the samel voltage.

E2.6. Carlos: Do they have the same voltage?

E2.7. Mirela: It's the same voltage.

E2.8. Manoel: Why is the battery so fat?

E2.9. Mirela: Because there are more electrons in there. It lasts longer.

E2.10. Carlos: Well. I think it is. It must be then.

E2.11. Manoel: No. It's 1,5 volt. Every battery is 1,5 volt.

Students viewed the task of comparing the prediction and the outcome of the experiment as a challenge. We see evidence of cognitive engagement in the investment employed in understanding the phenomenon in question (lamps with identical brightness when attached to batteries of different sizes). They articulated data and information they had available to explain the outcome. For example, they sought information on the potential difference of the battery (E2.5, E2.7 and E2.11) and articulated previous knowledge on the constitution of batteries and cells (E2.9).

In the first and third episodes there was also cognitive engagement, but in them the students prioritized the assembly of circuits to the detriment of the analysis and explanation of them. See the sequence of utterances below. There is an example of students' cognitive engagement in episodes one and three:

E1.1. Mirela: You have to make a circuit. Electrons have to circulate. Because if you make a short circuit...

E1.2. Carlos: It's going to burn out.

E1.3. Manoel: Is this a positive and a negative? [Points to the battery]

E1.4. Carlos: Of course! It's a battery.

E1.5. Mirela: It's the positive and the negative of the battery.

E1.6. Manoel: Positive and negative! But how are we going to know if current is going on?

E1.7. Carlos: If the light turns on, right?

E1.8. Manoel: Oh, there's a little lamp!

E1.9. Mirela: Get in there. You have to attach it to make the circuit. [Points to the lamp in Manoel's hand].

In this sequence of utterances of the first episode, students' cognitive engagement is focused on recognizing the materials and understanding what they should do in the task. To do this, they mobilize concepts such as circuit, short circuit, current and poles of a battery. In E1.9, Mirela directs colleagues to the task of assembling an electric circuit that turns on the lamp.

In the third episode, we identified indications that support our interpretation that G1 students prioritized circuit assembly to the detriment of their analysis and explanation. The following statements show that the students worked a few minutes to get two bulbs lit with a battery and wires. When they did, they celebrated and showed the teacher that the circuit worked. Faced with the teacher's question about the registration of the assembled circuit, Carlos revealed that the group's actions focused on attempts to set up the circuits:

E3.1. Carlos: Made! Now you see, right, Teacher A?

E3.2. Teacher A: But how are you going to draw it? You do not [inaudible].

E3.3. Carlos: No. We did an experiment just to experiment.

The actions of the teacher in the group were fundamentally aimed at maintaining or deepening students' cognitive engagement in tasks. This is because the teacher was able to perceive when the students failed to orient themselves towards the objectives of the task (he noticed, for example, that after setting up, they did not draw or explain the circuits) and decided to intervene in order to reorient the work of the group.

In the following lines, the students talk to the teacher at the end of the first episode. The teacher asked them to explain what made the lamp light up and how it worked:

E1.10. Mirela: There's an electron circuit.

E1.11. Carlos: [Inaudible].

E1.12. Manoel: That's because there's an electric current. Because of the potential difference.

E1.13. Teacher A: Uhm?

E1.14. Manoel: An electric current occurs because of the potential difference.

E1.15. Teacher A: Alright. There's an electric current. And?

E1.16. Manoel: The electric current will light the lamp. [Meanwhile Carlos shows Mirela how the electric current runs through the lamp]

E1.17. Teacher A: How?

E1.18. Manoel: I do not understand.

E1.19. Teacher A: How is the electric current going to light the lamp?

E1.20. Manoel: Because when the electric current passes, the electric current is hot. It will heat the tungsten wire until it hits, I do not know how many thousand degrees. Then it emits light.

E1.21. Teacher A: Okay. What do you think of his explanation here?

E1.22. Manoel: They did not hear. [Carlos and Mirela were distracted, manipulating the materials]

E1.23. Carlos: Hi? Repeat, Manoel.

E1.24. Manoel: An electric current passes through the tungsten wire, it heats up, turns red and emits light.

E1.25. Carlos: Ah, unprecedented explanation!

E1.26. Teacher A: Wait there. There is a detail. You say that the electric current ...

E1.27. Manoel: Warm up the tungsten filament.

E1.28. Carlos: It's because the tungsten wire is a resistance to the current. As the resistance goes there and ...

E1.29. Manoel: Yeah, huh? The electrical resistance of tungsten wire.

E1.30. Teacher A: Was that what you were talking about?

E1.31. Manoel: [Inaudible] The business is more farfetched. I said it will work because it will generate heat.

E1.32. Teacher A: So describe it.

When intervening in the group, the teacher launched a challenge that was not foreseen in the activity script, but it helped the students in the task of understanding the assembled circuits: explain the operation of the incandescent lamp. The students recognized that the electric current that runs through the circuit is responsible for lighting the lamp. However, they do not explain why this occurs. Between E1.10 and E1.14, the students gave indications that they were cognitively engaged in the task and in the challenge posed by the teacher as they resorted to electricity concepts to try to explain the operation of the lamp. The question posed by the teacher in the utterance E1.15 contributed to keeping students cognitively engaged. From it, Manoel expressed his understanding about the operation of the lamp with the proposition of an explanatory model. At the same time, Carlos and Mirela discussed the path traveled by the current inside the working lamp. At utterance E1.21, the teacher rearranged the group's work so as to involve all students in the same discussion. For this, he tried to get Carlos and Mirela to perceive and discuss the inconsistency in the model proposed by Manoel in E1.20. The teacher's action favored the participation and involvement of the three students. Their effort to respond the teacher's questions made them reach higher levels of understanding on the subject, suggesting that there had been cognitive engagement of the students in the task.

GROUP G2: ANDRÉ, RENATO E VALTER

The three boys of G2 were very participative, but also agitated and vain. There was among them a dispute over the leadership of the group. This led them to experience difficulties in joining forces and coordinating initiatives to solve the tasks of the activity. Valter was shy. He struggled to contribute to the development of the tasks, but had difficulty making himself heard by his colleagues. So he did not participate in the group discussions at many points. On the other hand, he was very observant and attentive to what happened during the task-solving processes. The effort expended to comprehend and work them well was perceptible. This helped Valter realize important things that enabled him to give his opinion, despite being more timid and the resistance of his teammates.

We observed that the group engaged in the tasks on simple electric circuits in the behavioral dimension. They had difficulty engaging in the cognitive dimension in view of the characteristics of their emotional engagement.

The indicators we could put together about behavioral engagement in G2 are more at the level of individual action than at the level of collective action. The students, individually, became involved and presented contributions to solve the tasks. They showed persistence, for example, when trying to make the electrical circuits work (lamp to light up). Each of them seemed imbued with the purpose of doing well what was proposed by the activity script. However, we did not perceive concern or care by the members of the group in establishing a dynamic of collaborative work. The students were not successful in considering and coordinating the individual contributions made to the tasks. This can be seen, for example, in this sequence:

E1.1. André: Put over here. The light bulb.

E1.2. Renato: I know what you're trying to do.

E1.3. André: Renato wants to try it on his own ... Go on.

[Brief silence]

E1.4. André: Easy, Renato.

E1.5. Renato: André, hold there. Give me that...

E1.6. André: I touch it!

E1.7. Renato: No! Do this: hold one of the thinglies and I'll take care here.

E1.8. André: Go on.

E1.9. Valter: Not on this side, Renato.

E1.10. Renato: You have to touch the lamp's little black metal.

E1.11. André: Wait a second! [Valter tried to get the materials]

E1.12. Renato: You have to create a circuit!

E1.13. Valter: Renato, hold it here. And this one here, here.

E1.14. Renato: You have to create a circuit.

These utterances are from the first episode of the activity, when students were dealing with the task of lighting a bulb with one battery and one wire – one at a time. All students have committed to the task – with active participation in circuit assembly – which is an indicator of behavioral engagement. But these utterances also point to the kind of situation that has repeatedly diverted students from collaborative work: the dispute between André and Renato for the group's leadership. The quarrel between the two was intense and apparently unconscious. There were situations where the students acted with a certain amount of aggressiveness (by pulling materials from the colleague's hands, for example). Although it is important for a leader to coordinate, orient and value the contributions of the other members of the group, in G2, André and Renato had difficulty managing their desire to take on this role. This generated numerous conflicts, made it difficult to include Valter in the discussions and impoverished some good learning opportunities.

Students may not have realized that they fueled a dispute during the entire class and how much it was detrimental to the group. Notice that, in utterance E1.7, Renato proposed a system of work involving André. This attitude made it possible, momentarily, the end of the dispute and the participation of the colleague. Renato allowed the momentary administration of the conflicts, created conditions favorable to the participation of the other students and contributed to the advance of the group. This behavior is expected of the leadership, but this situation did not repeat. From E1.7, Valter saw an opportunity to participate with colleagues in the task resolution. Although he stayed away from the beginning of the discussion, he remained attentive to what his colleagues did. In E1.9 and E1.13, Valter indicated the correct way of connecting the wires. It is worth noting that, although they had softened the dispute between themselves, André and Renato could not pay attention to what the colleague told them. In utterance E1.13, Valter decided to show with his hands how the connections should be, which was very important for the group to turn on the light bulb.

The emotional engagement of the students of the G2 group in the tasks is evidenced in a special way by these situations of dispute for the leadership between André and Renato. In addition, in the resolution of tasks, their actions were marked by a mixture of excitement, agitation and nervousness. These emotional reactions associated with the priority given to the assembly of circuits to the detriment of their analysis and explanation seemed to us to be decisive for the difficulties of the two to engage cognitively in the process of task resolution. We have not identified any evidence of cognitive engagement in their actions. Valter's emotional engagement, in turn, was marked by reactions of frustration and nonconformity with the attitudes of colleagues and the fact that he was ignored in the midst of this dispute. However, the fact that Valter watches the dispute, without taking sides, may have given him time to reflect on the ongoing tasks. His few interventions in the discussions were precise and decisive for solving impasses. There is a possibility that the success of Valter's proposals is associated with an investment in understanding the circuits studied, which would be an indicator of his cognitive engagement in the activity.

Take, for example, what happened when the students of G2 tried to light the lamp with only one wire and one battery in the first episode:

E1.40. André: I know how to light the bulb with a single battery. [Light the bulb with one wire].

E1.41. Renato: I know too.

[Seconds later ...]

E1.42. André: Here, Valter. You have to help me connect here. It was easier with one wire...

E1.43. Valter: Hey, André ...

E1.44. André: Connect here! I'll try to do with a single battery. With only one wire.

E1.45. Renato: [Inaudible].

E1.46. André: It has to be done with a single wire!

E1.47. Renato: Where is it said you have to do with a single wire?

E1.48. André: But I can do it with only one wire.

E1.49. Renato: You're going to sketch. If Andre does it wrong, he will sketch alone.

E1.50. Valter: And how is it going to flow ???

E1.51. André: See? Weak head. I'm the guy!

In this utterances, André faced the challenge of lighting the lamp with the battery and only a wire. Such a challenge was not set out in the activity script. Other groups had already tried the same. Probably he realized this and decided to make his own attempts. Renato did not take up the challenge because it was not included in the script and was not proposed by the teacher. From E1.48 onward, one can perceive evidence of the dispute between André and Renato. Such disputes did not value the learning opportunities created in the group. Valter from the beginning was attentive to everything that happened. In E1.43 he tried to intervene without success. In E1.50, Valter made an issue that we interpret as being driven by the quest to understand the "path" of the electric current or, in other words, the electric circuit that would be established. This shows his cognitive investment in understanding the phenomena in question.

GROUP G3: ANDREZA, CECÍLIA, JOÃO E MAX

The four students were attuned. They managed to organize the work well in the group, which gave fluidity to the development of the tasks. We did not identify any kind of rivalry. We also did not identify depreciation attitudes of one member over another. All participated actively in the resolution of tasks. It should be noted that João and Andreza were repeat students.The students have fully engaged in the process of problem solving in the behavioral, emotional and cognitive dimensions. Behavioral engagement was characterized by individual contributions, collaboration, commitment and persistence in the process of task development; by their commitment to each other – both in the reception and discussion of ideas and in actions aimed at maintaining the members' engagement in the group. All of this was made explicit as they discussed and planned the assembly of the circuits, proposed new ways of making the connections and were concerned with understanding what allowed and what impeded the proper functioning of the circuits. The ideas exposed, however strange, were debated in a respectful way. A striking feature of the behavioral engagement of these students could be observed when some of them stopped collaborating to approach the tasks. For example, João was involved in situations of this kind, either by setting up a circuit alone or by leaving the room with impatience when discussions were lengthened or resumed. Such situations were rare. When they occurred, they were immediately confronted by group members: they caught the attention of those who deviated from a collaborative work scheme or tried to include that member in the system they held for task resolution.

Emotional engagement of the students was evidenced by the satisfaction in accomplishing the tasks. The way the group has organized seems to have contributed to the well-being of the students. One example of this is in the following sequence of utterances. It was drawn from the third episode as students discussed how they would report the activity in development:

E3.1. João: How's it going to be? Does each one do yours or will we act together to do it?

E3.2. Cecilia: Each one makes ones own.

E3.3. João: If you want to get together to do it, we can stay [inaudible].

E3.4. Andreza: I think it's easier to score 1.2 [higher grade] if we work together. Did you see how many ideas that were popping up here while we're talking?

E3.5. Cecilia: It is up to you.

E3.6. Andreza: Let's stay here Tuesday to do.

João consulted his colleagues if they would work the report together. At first, Cecilia preferred to do it by herself. However, João's positioning in E3.3 and Andreza's argument in E3.4 seem to have disarmed Cecilia. The indicator of emotional engagement in this sequence of utterances is in Andreza's argument that shows satisfaction with the result of the collaborative work in the group.

The work system established by the group and the emotional involvement of the students with the tasks were favorable to the cognitive engagement. Unlike the other groups, G3 also cognitively engaged in the search for an explanation for the assembled circuits. Getting a lightbulb to lit, excited them, as happened with the other groups. However, the students of G3 did not limit themselves to this: they also described and tried to explain what allowed or what prevented the operation of the circuits they set up.

Following is a dialogue from the first episode that highlights students' cognitive engagement. We note here that they sought to understand the operation of the circuits they set up:

E1.1. Andreza: And why does it not light here? Is it because the place for it receiving energy is that part out here? [pointing to the connections between the lamp and the battery]

E1.2. João: I think it is, right?

E1.3. Andreza: What do you think, Cecilia?

E1.4. Cecilia: I think that's it. In the other circuits, which did not light, it is because they were not in contact with ... How do you say?

E1.5. Andreza: The circuit was open.

E1.6. Cecília: No...

E1.7. Andreza: Oh, yeah. If the circuit has no contact ...

E1.8. Max: Maybe the lead wire can not transmit power.

E1.9. Andreza: No. If the lead wire is touching here, and here, and it's connecting here, it will *always light up. Unless this part is connected here. If you have that part here, the bulb turns on. But now, if it is open, if it does not have both parts of it connecting here, transferring energy, there is no way it will do.*

The discussion was initiated by Andreza, who presented a question about how to set up the circuit in order to light the bulb up. This made the students present their understanding of how the circuit works and what it took for the light to come on. There was a joint discussion between all the members leading them to realize that the lamp would turn on when connected to a closed circuit. In this discussion it becomes clear the cognitive investment directed towards understanding the circuit setups.

Another interesting aspect of this sequence of utterances, which has been repeated at various times, is Andreza's care in involving his colleagues in the discussions. In E1.3, she tried to listen to what Cecilia had to say about the circuit setup. The attempt to give a collective dimension to the discussions led the group to experience good learning opportunities. For this reason, we affirm that this characteristic of Andreza's behavioral engagement favored both the behavioral engagement and the cognitive engagement of all the group.

GROUP G4: HELENA, LUIZ E MICHEL

Michel and Luiz were quite agitated and inattentive. They were not committed with their own learning, with Helena's learning and with the development of the group. Michel was respected by his colleagues. He led the task-solving process. However, his leadership was guided by the interest in, as soon as possible, to be free of the activity. Luiz supported Michael's actions, which strengthened his leadership. Helena seemed to be hard-working, focused and organized, but unsure of what she knew. This put her in a situation of fragility compared to her colleagues: frustrated and without resistance, Helena began to guide her actions by the work dynamics established by Luiz and Michel.

The type of relationship that the G4 students established with the activity was very different from what we observed in the other groups (G1, G2 and G3). Michel's leadership and his partnership with Luiz were decisive for the disengagement of the members of the group in the activity.

Michel and Luiz worked in an attempt to solve tasks that integrated the activity. At first glance, this could be taken as an indication of behavioral engagement. However, a closer look revealed that these students behaved as if the activity were a game from which they wanted to be free as soon as possible. This, for example, is evidenced in the first episode when Michel proposes a division of tasks to speed up the work to be developed:

E1.16. Michel: We could divide it up. Each one makes a portion.

E1.17. Luiz: Wow! It's big!

E1.18. Michel: One does from 1 to 5, the other from 7 to 9 and I do 11 and 10.

In suggesting that each member of the group did a part of the tasks and challenges, Michel did not commit to establishing a collaborative working system, did not value the group as a space for discussion and did not show involvement in the resolution of tasks. The two boys did not read carefully the script in order to find out the proposed tasks. On more than one occasion, they invented answers or described in the notebook procedures not performed as a way to avoid work, but to obtain a product to be presented to the teacher at the end of the lesson. These attitudes show that the lack of motivation of some students may be such that they can not engage even in an activity that captivates most of their peers by having playful and intriguing ingredients. We consider this as an indication of both behavioral and emotional disengagement.

Helena began the class behaviorally and cognitively engaged. She (i) demonstrated effort, concentration and attention in the resolution of tasks; (ii) tried to read the script and understand what was asked; (iii) tried to contribute to the development of the group by alerting colleagues about what was requested in the activity; (iv) demonstrated cognitive investment in the understanding of assembled circuits. Although ignored by colleagues during the resolution of the tasks of the first episode, she did not fail to pay attention to what happened in the group and to reflect on the actions of colleagues.

Despite her efforts, Helena did not have the opportunity to participate in the discussions led by Michel and Luiz. The colleagues, in addition to not listening her, made it difficult for her to participate in the circuit setup process. We will base this statement on an example that we extracted from the first episode. Observing the repeated unsuccessful attempts by Michel and Luiz to light the lamp, Helena attempted to participate:

E1.1. Helena: Let me try, Luiz ?!

E1.2. Luiz: Get more there. There is plenty there.

This situation exemplifies well the way Michel and Luiz related to Helena. In that case, Helena asked for a chance to try to mount a circuit with the lamp. Luiz denied it and suggested that his colleague should take more materials from the teacher's workbench.

We inferred that Helena, in making such a request, had an idea of how connections between the components of the circuit should be made. It seemed to us that she not only noted, but also sought to understand what her colleagues were doing. We take this as an indication of her cognitive engagement in the task. This interpretation is reinforced by what followed the dialogue above: Helena was able to pick up the materials on the bench in a moment of distraction from her colleagues and lit the lamp after a few attempts.

The classmates did not like to see Helena manipulating the materials. The following sequence of utterances illustrates how Michel and Luiz acted in the face of this Helena action:

E1.3. Michel: Give me a bulb there!

E1.4. Luiz: I ... [inaudible]. [looked for the bulb on the workbench]

E1.5. Michel: Where's the light bulb? Did you give Helena this bulb?! [In reproachful tone]

Helena's interventions throughout the first episode of the activity focused on the group's own development and development. However, this way of acting did not continue throughout the lesson. Helena saw that her ideas and proposals were not well accepted by her colleagues. From the second episode onwards, she disengaged herself and began to act in the same way her colleagues did.The second episode contains situations that reinforce what we have said about the group. In it, students should predict, observe, and explain the brightness of a light bulb attached to batteries of different sizes. Michel prepared an incorrect prediction without the participation of Luiz and Helena. He presented it to the teacher instead of discussing it with his group mates:

2.1. Michel: Look at three [script question 3] ... It would not shine, eh ??? Teacher B, with the little battery does the bulb light up?

2.2. Teacher: B: What?!

2.3. Michel: It doesn't, does it?

2.4. Helena: Try it out!

2.5. Michel: Here, look. The three. The small battery instead of the medium one.

2.6. Luiz: What a clever question, did you see?

2.7. Helena: Where is the bulb?

2.8. Michel: Come on, Teacher B. Let him go. [Teacher: B was talking to a student from another group]

2.9. Michel: The small battery instead of the medium one. It wouldn't shine

2.10. Teacher: B: The brightness of the light bulb. It's the brightness. If you changed the bulbs...

2.11. Michel: I would not ... [inaudible].

2.12. Teacher: B: Unn? What do you mean? You are saying...

2.13. Helena: It lit up. It lit up.

2.14. Michel: No. We used this [average battery]. It had to be the little one.

2.15. Helena: Ah, the little one.

2.16. Michel: One smaller.

2.17. Teacher: B: Ah, why?

2.18. Michel: Because I was not going to have enough energy.

2.19. Teacher B: Oh yes? What is the voltage of the battery? Have you ever used that little battery? What's its voltage? It's 1,5V.

Michel seemed uncertain of his prediction. He did not want to discuss it with Teacher B, but confirm that it was correct. At E2.4, Helena wanted to set up the circuit to observe the brightness and compare with Michel's prediction, but he ignored her proposition and continued to address Teacher B. Helena even set up the circuit but was unable to observe the results and discuss them with her colleagues. The conversation with the teacher, especially E2.19, seems to have contributed to Michel's realization that his prediction was incorrect. [Michel realized] That, in fact, the brightness of the lamp would be the same when plugged into piles of different sizes. Michel used this information to record in the notebook his answers to questions 3, 4 and 5 of the script, although they did not make the comparison between prediction and result.Helena drew the attention of colleagues to the need to assemble the circuit, observe the brightness and compare with the observation results with the forecast. For having inferred the correct answer from the conversation with Teacher B, Michel suggested "pretending" that they had made the observation:

E2.20. Helena: The [question] four [of the script]. Your prediction about ... No ...

E2.21. Michel: It was correct.

E2.22. Helena: Here! [pointing to the script]

E2.23. Michel: Wasn't the brightness the same?

E2.24. Helena: But look here: Set up the circuit using a small battery instead of an average size one. Mount the circuit using the small battery instead of the medium one.

E2.25. Michel: No problem. Pretend we did. Pretend...

E2.26. Helena: OK. Got it. That's right.

From E2.26, Helena reduced her attempts to participate in the process of solving the tasks proposed in the activity. She went on to write down Michel's answers or to elaborate answers based on the speeches of colleagues. When Michel and Luiz stopped answering some question in the notebook, they copied what Helena wrote.

END REMARKS

We characterized the engagement of first-year high school students who worked as a group in an investigative activity on simple electrical circuits. We did these observations for four groups of three to four students.In the four groups investigated, the students became involved with the electrical circuit activity tasks. This could be interpreted as evidence of engagement. We saw, however, that not all students engaged, and that among those who did, there were significant variations in the quality of engagement. Our results suggest that behavioral engagement is a prerequisite for its cognitive dimension: the students' minimal behavioral involvement with school tasks, for example, by observing the norms of classroom functioning, by the effort to solve tasks and by respect for ideas and proposed resolutions in the group, it is necessary to establish conditions favorable to the cognitive investment in the understanding of what is put as object of study. On the other hand, there is a curious and non-intuitive situation: there may be behavioral engagement without full cognitive engagement in the activity. Such a situation can occur when students act exclusively or partially oriented by personal demands, diverging to a greater or lesser extent from the tasks proposed in the activity. This finding of ours is in line with the results of Julio, Vaz e Fagundes

(2011) and of Borges, Julio e Coelho (2005). The first work also reveals situations of students engaged in behavioral activity as a whole, but not in the tasks proposed by the teacher. This was seen in situations where engagement was driven by personal interests rather than the objectives of the proposed tasks. The second work, however, reveals that only behavioral engagement in the physics discipline does not guarantee better school performance in this discipline. This requires cognitive engagement as well. This result reinforces the idea that the occurrence of behavioral engagement does not guarantee cognitive engagement.

In the context in which this research was conducted, we realized that the emotional dimension of engagement was associated with: the feeling of well-being occasioned by the opportunity to participate in the search for a solution to the tasks, or by the perception of good performance in the tasks ; and also to emotionally draining feelings such as frustration and agitation arising from disputes between group members for task resolution.

The analysis of the engagement of the four groups of students revealed two elements of the context of activity development that seemed to relate to the quality of the students' relation to the tasks: the interactions established between the group colleagues and the way the students handled the tasks.There is, in the research literature, results that reveal that engagement in school tasks is influenced by issues related to student interactions (ADEGOKE, 2012; KINDERMANN, 1993; SHERNOFF *et al.*, 2015).We identify that the action level in which the engagement takes place – whether individual or collective – has a direct impact on the quality of the engagement. The engagement of members of a group is more forceful and multidimensional in character when all or most of these members work on the tasks in a collective action plan, even when there are in the group adverse situations such as some degree of dispute between members or escape from tasks. Work on the collective action plan occurs when students perceive themselves as part of a group and assume co-responsibility for developing quality work in which the other is seen as part of the task-solving process and therefore cared for, valued and included at all stages of this process. The engagement of the members of a group tends to have its multidimensionality compromised and to be less vigorous when the work in the tasks occurs in the individual level of action. In these cases, students may even demonstrate engagement in the behavioral and cognitive dimensions, but the quality of this engagement is compromised by the lack of collaboration to approach the tasks and by the non-sharing of understanding about these tasks and the phenomena framed by them. We also identified that the way students handled the proposed tasks influenced the quality of engagement. The tasks that constituted the activity required assembly, description and explanation of simple electrical circuits. Students in the group which has observed these three demands have engaged in the behavioral, emotional, and cognitive dimensions. The quality of cognitive engagement was highlighted because, in describing and explaining the circuits, the students demonstrated a clear investment in understanding the phenomena framed by the activity. On the other hand, the students of the groups that only observed the demand of assembly of the electric circuits also presented multidimensional engagement, but the cognitive dimension of their engagement was limited. We understand that this limitation in the cognitive dimension occurred because the students prioritized the assembly of circuits to the detriment of their descriptions and explanations. The tasks of describing and explaining the circuits had a great potential to increase students' cognitive engagement in a similar way to that of G3 students. However, this potential was not used by the other groups. Therefore it is very important the monitoring by the teacher of the engagement of students throughout a learning activity. Such monitoring can enable students to become aware of the tasks assigned to them and to direct their engagement in these tasks. Directing all work by specific tasks of an activity can divert students from good opportunities for cognitive engagement and hence learning.

This study has implications for physics education research and also for physics teaching once it illustrates the use of the concept of engagement for the observation and analysis of students in real teaching and learning situations. The behavioral, emotional, and cognitive aspects of engagement are dynamically interrelated as highlighted by Fredricks, Blumenfeld e Paris (2015). Although these dimensions do not separate, according to these authors, for the purpose of analysis, the characterization of each of these dimensions separately brings the gain of allowing one to look over each one of them. This may be of interest to teachers seeking new tools for monitoring or evaluating learning processes, as well as researchers who wish to investigate student engagement based on classroom observation techniques.The use we made of the concept of engagement in this research report ends up showing how it can be used by the teacher in class. We are also teachers. So we know that in real time, there is no way to analyze what happens in each group in the way that research time allowed us to do. It was nuances of speech and details of behavior that allowed us to perceive who was cognitively engaged and when. We have seen that students in the G4 group, for example, have simulated some kind of involvement with the task. During the lesson, the teacher probably did not notice it. However, our description of that group may serve teachers who are engaged in designing strategies for assessing and monitoring the development of activities by students. Once we could perceive nuances and details based on the concept of engagement, this concept can be invoked when one of these teachers notices differences in the responses of the members of a group that he or she will attend in class. If the teacher knows that having the students involved in the task is a necessary but not sufficient condition to consider that they are engaged, he also knows that he needs to pay more attention to the type of involvement, the nature of the actions, the content of the speech, and to others aspects of student performance. If the goal of teaching is learning and learning is a function of cognitive engagement, it is not enough to get students engaged. It is necessary to work for students to engage in tasks in three dimensions: behavioral, emotional and cognitive.

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Submitted on 19/06/2018
Approved 07/01/2019

Contact:
Prof. Dr. Alexandre F. Faria
Universidade Federal de Minas Gerais
Colégio Técnico - Setor de Física
Av. Antônio Carlos, n. 6627 - Bairro Pampulha
CEP 31270-901 - Belo Horizonte, MG - Brasil

APPENDIX: LAB11 – SIMPLE ELECTRIC CIRCUITS

Material: medium size batteries, light bulbs, wires, socket for bulb.

Part 1 - Single circuit with a light bulb

The first activity for your group is to assemble a simple circuit using a medium battery (AA) and wires, to light a small bulb. Pay attention to how the components are connected.

1) For each attempt your group makes, draw a picture showing how the bulb, battery, and wires are connected. Indicate whether the lamp has glowed or not.

2) After you can light the lamp, examine the drawings you made in the previous attempts. Can you see what was wrong with the previous circuits? Explain.

Answer question 3 before doing any other assembly.

3) What would happen to the brightness of the bulb if you were using a small battery instead of the average battery? Explain your reasoning.Mount the circuit using the small battery instead of the medium one.

4) Was your prediction about the brightness of the light bulb correct? Describe and explain what you noticed.

5) Does the size of the battery influence the brightness of the bulb? Explain your reasoning.

Part 2 - Single circuit with two light bulbs

6) Now think about how you should do to add a second light bulb to the circuit making them light up at the same time.

7) Draw each circuit that your group has set up to succeed. Try to explain why the lamps have lit up or not with each of the assembled circuits.

8) What would happen to the second lamp if the first lamp burned or was switched off? Explain.

9) How would you turn off the first light bulb? Do this and see if the result is according to your expectation. Describe what happened and explain any disagreement with your prediction.

10) Is there any other way to add a second light bulb to the circuit? How?You may have noticed that lighting circuits in homes and buildings are constructed so that if one light bulb burns or shuts off, not all others are affected. That is, other bulbs can be switched on or off independently. In this type of connection the lamps are connected in parallel. Try to draw what it would look like with two lamps. Try to assemble it. Make sure that if you turn off one light bulb, the other remains on.

11) Another way to connect the bulbs is in series. One is attached after the other. The difference is that if one of them burns or is turned off, the other one stops working. In the same way, in a series circuit the bulbs are either switched on or both switched off. Assemble the bulbs in series and observe this.

12) What do you notice about their brightness?