Chapter 11
The Design of Activities Based on Cognitive Scaffolding to Teach Physics

Genaro Zavala

Abstract Physics education research has produced many educational strategies such as Peer Instruction, Tutorials in Introductory Physics, and Real-Time Physics which one of the main objectives is to help students organize a better knowledge structure. For some settings, because equipment is needed for some of those strategies, then they are difficult to implement. This contribution recommends designing cognitive scaffolding activities without equipment in order to help students to choose the right scientific concept for the problem at hand. Cognitive scaffolding activities include strategies (i.e., by pumping questions) that help students reflect, think, or conceptualize. I present the framework in what the activities are based and describe a process of the construction of an activity for the understanding of the superposition principle applied to electric fields in a typical electricity and magnetism, first-year university course. At the end I present results implementing the activity with students by showing students' responses and reasoning to a problem in a midterm exam.

11.1 Introduction

In university-level teaching of physics, there are a number of active learning strategies that are based either on a format with a large number of students such as Peer Instruction (Mazur 1997) or on a format with a small number of students like laboratory-based strategies such as Tutorials in Introductory Physics (McDermott et al. 1998) and Real-Time Physics (Sokoloff et al. 2004). In many Latin American universities, the setting in which physics is taught is neither of those. In many of these universities, the number of students in sections is between 30 and 40. Moreover, classrooms in which these courses are taught could be in different buildings through the university. Although Peer Instruction or even Tutorials in Introductory

G. Zavala (✉)
School of Engineering and Sciences, Tecnologico de Monterrey, Monterrey, Mexico

School of Engineering, Universidad Andres Bello, Santiago, Chile
e-mail: genaro.zavala@itesm.mx

M. Pietrocola (ed.), *Upgrading Physics Education to Meet the Needs of Society*,
https://doi.org/10.1007/978-3-319-96163-7_11

Physics have been proven to be effective in this kind of settings, sometimes it is unpractical to have equipment needed for the strategy, clickers in the case of Peer Instruction and some equipment or a lot of that in the case of Tutorials in Introductory Physics and Real-Time Physics, respectively. We have been working on the design of problems based on cognitive scaffolding to teach physics. These problems are designed to be used in almost any setting since no equipment is needed. Students work in collaborative groups of three or four students each. The design consists of either (1) taking alternative conceptions students normally have and design a tutorial-format conceptual sequence to organize the knowledge structure of students related to that conception and (2) transforming a traditional problem to a tutorial-format problem which takes the student through scientific reasoning steps to build concepts, that is, a type of cognitive scaffolding (Mackiewicz and Thompson 2014). The objective of this contribution is to show the framework in what the activities are based and, at the same time, describe a process of the construction of an activity.

11.2 Background

In order to solve problems, students should choose from their own knowledge structure what concepts are related to the problem at hand and then choose a learned solving path to get to the solution. However, many times the students' knowledge structure is ill-defined with both scientific and alternative conceptions coexisting at the same time which make difficult to students to choose the right conception needed for the problem (Posner et al. 1982). The alternative conceptions students might acquire in their daily life or learned from not well-understood education during their previous years at school (Hammer 1996). Some research suggests that if a student chooses the scientific conception for the problem, there is more probability that the right solution is obtained, but if he/she chooses an alternative conception, then the result might not be the correct (Ling and Singh 2015).

There are many educational strategies such as Peer Instruction (Mazur 1997), Tutorials in Introductory Physics (McDermott et al. 1998), and Real-Time Physics (Sokoloff et al. 2004), to name a few, which one of the main objectives is to help students organize a better knowledge structure by working in pairs or in collaborative groups. For some settings, those strategies are difficult to implement. There is then a need to design activities in which instructors can implement without equipment. One way to design activities in order to help students to choose the right scientific concept for the problem at hand is using what has been called cognitive scaffolding (Mackiewicz and Thompson 2014) or simply scaffolding (Wood et al. 1976). Paraphrasing Wood, Bruner, and Ross, scaffolding is any process that enables the student to achieve an understanding of a scientific conception, solve a problem, carry out a task, or achieve a goal which would be beyond him/her if not assisted. Scaffolding could be given by the instructor or by peers, but also it could be given in the activity they solve. Cognitive scaffolding includes strategies (i.e., by pumping questions) that help students reflect, think, or conceptualize (Mackiewicz and Thompson 2014). In physics education research, scaffolding or cognitive scaffolding has been used for some years (Cui et al. 2005; Singh 2008; Garza and Zavala 2010;

Lisdstrom and Sharma 2011; Ding et al. 2011; Roll et al. 2012; Leinonen et al. 2013; Ling and Singh 2015).

11.3 Design of Activities

We have worked in two types of activities in which we used cognitive scaffolding. The first type of activities helps students to acquire scientific conceptions instead of alternative conceptions they might have. The main objective for this type of activities is precisely substitute, if possible, a strong alternative conception by a scientific-accepted conception. For this type of activities, we follow the following chart (Fig. 11.1).

In brief, (1) an alternative conception is chosen from the vast literature in the topic or from the experience that the instructor has with their own students during the years. The conception should be something that it is well known and strong enough that students could hold into it even after instruction. (2) A literature review is always a good practice to do since research articles not only normally explain what the alternative conception is related to and some actions one could take but also, from these articles, a situation could be found or ideas to think about a physical

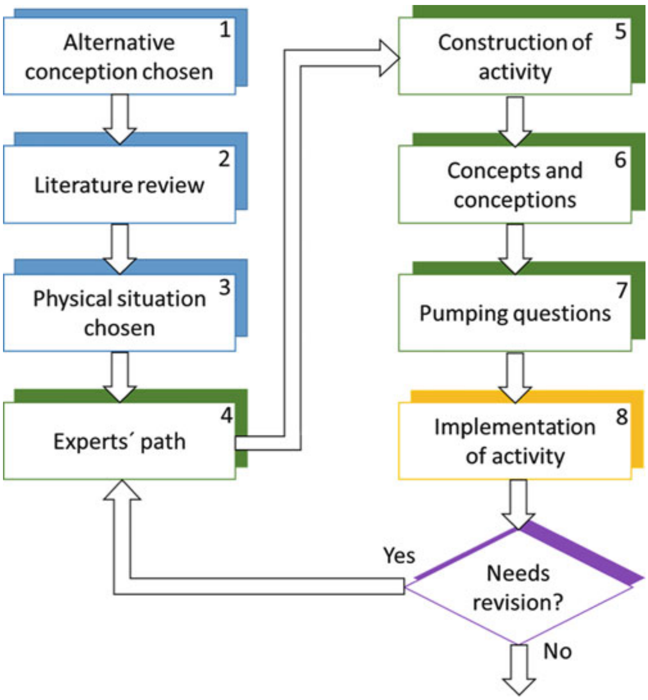


Fig. 11.1 Sketch of how an activity is designed to acquire an accepted scientific conception. The iteration could be as many as needed to have an activity that succeeds

situation could be found. Then, (3) a physical situation is chosen according to the alternative conception. It is important that the situation is familiar to students either from their daily life or academically. (4) The following step is to think and design an expert's path to solve the situation. In this case, the path could be made of a few questions or more, depending on what initially students understand. With the expert's path, (5) construct the activity trying to follow that path as close as possible. In each question, think of additional (6) concepts and conceptions students should have to continue. If students have acquired those concepts, continue. If not, then you have to propose one or more questions in which this concept or conception is acquired. (7) Design some pumping questions to make students reflect on their own learning before continuing. This could be achieved by questions that make them analyze their own answers and/or contrast two answers to different parts of the activity. (8) The last step before assessing is implementing the activity in a real situation inside the classroom. A better way to have feedback on how the activity helps students to acquire a scientific conception is to implement and interact with students to get that feedback. After implementing, you should ask yourself whether the activity needs revision or not. If it does, then return to review the expert's path and go on from there. If the activity was a success, then it might be ready.

The second type of activities takes a traditional end-of-the-chapter problem and transforms it into a problem in which scaffolding is given. The design process is similar to the previous type. However, in this case, the situation is what the problem presents. Another difference is that in these types of activities, the objective is not a specific alternative conception, but to help students to refine their problem-solving skills by understanding the scientific conceptions they should choose in their process.

11.4 Examples of Activities

The example in this section is an activity in the topic of electrostatics of the first type presented above. The activity tries to help students to understand the scientific conception of a conducting neutral object in terms of its capacity to produce an electric field. Some students have the alternative conception that neutral conducting objects (or in general that neutral objects) are not able to produce electric field no matter what. Garza and Zavala (2010) worked on this conception trying to see whether scaffolding improved students' understanding. They presented evidence that, in effect, some scaffolding produced better results.

Contextual Background The activity can be implemented in a university introductory electricity and magnetism class. The first topic in the course is electrical interactions in electrostatics. The activity needs students to be familiar with the induction of charge and the condition for electrostatic equilibrium as well as the superposition principle. The activity is implemented with students in any setting but in collaborative groups of three students each. This ensures that not only the activity or the instructor with interactions with groups provides scaffolding but also that peers also provide some scaffolding (Ge and Land 2003).

Description of the Activity The activity is presented in Appendix (without blank spaces that normally need student's responses). The activity starts with Section I which has the objective to present the simplest case, an isolated neutral conducting object. Students, in general, do not have a problem with the correct answer in this section since, even those with the alternative conception will have this answer correct. However, there are three questions which serve as cognitive scaffolding since the instructor and peer interactions make students understand that the cube is by itself, i.e., far away from any other object; that even though the object is neutral, it has charge (the same number of positive and negative charges); and that this charge is free to move if an electric force is present. The second question then is introduced and is expected that students answer that there is no electric field at location P and this answer is reserved for contrasting later on the activity.

Section II presents another situation with a nonconducting object with excess charge on the surfaces. The first questions are similar to those in Section I to make them reflect on what a nonconducting object is and that the sum of the negative and positive charge is zero. The situation serves as scaffolding since later on, when there is an induced charge on a conducting object, the distribution of charge will be similar to the object in this section. Students must get to the conclusion that, even that the object is neutral, because the negative charge is closer to the location, then, the electric field will exist at that location.

Section III is the heart of the activity. First, a point charge is isolated in the space, and because students have previously seen the electric field produced by point charges, then the question of the E-field at location S is not a main issue. Then, a neutral conducting object is placed next to the point charge. Question 2 is an example of resorting to concepts and conceptions that are not the main subject of the activity but that we think it is important to reinforce. In the same way is question 3 since it serves to resort to a concept that students should have and reinforce that concept as in question 2 in this section. However, it is also a pumping question for scaffolding since the charge distribution of students should be similar to the charge distribution presented in section II. Question 4 is a pumping question that serves as part of cognitive scaffolding since it makes students reflect on their own thinking and whether that thinking is consistent to previous questions. Question 5, similar to questions 2 and 3, is another question to reinforce concepts and conceptions. Question 6 is another example of scaffolding since it helps students to think about the electric field produced by the charge but also the electric field produced by the cube. Lastly, question 7 is another example of cognitive scaffolding since students reflect on a main issue of the activity, that is, the neutral object producing a field.

Section IV is the conclusion part of the activity. Questions 1 and 2 have different answers of the electric field produced by the same object which is neutral and conducting. Therefore, students should realize that, in the second case, there is an electric field produced by the neutral object. The last question is cognitive scaffolding since it makes students reflect on their own answers and come to a correct conclusion.

In a broader view of scaffolding, that is, construction of concepts and conceptions from the simpler ones to more sophisticated ones, the following activity that an instructor might assign is similar to the previous described activity, but in this other case, instead of having a neutral conductor, the new activity might use a neutral nonconducting object. At the end of the new activity, students understand that in the case of nonconducting materials, the polarization plays a similar role to the induction of charges in conductors.

11.5 Students' Responses in a Summative Evaluation

The activity presented is successful for students to acquire the scientific conception of electric fields produced by neutral conducting objects. In a midterm evaluation a month later, a similar problem was presented for students (see Fig. 11.2).

There were a total of 31 students who were in the course and presented the exam. Out of 31 students, 10 of them answered the 3 questions correctly, and 12 of them

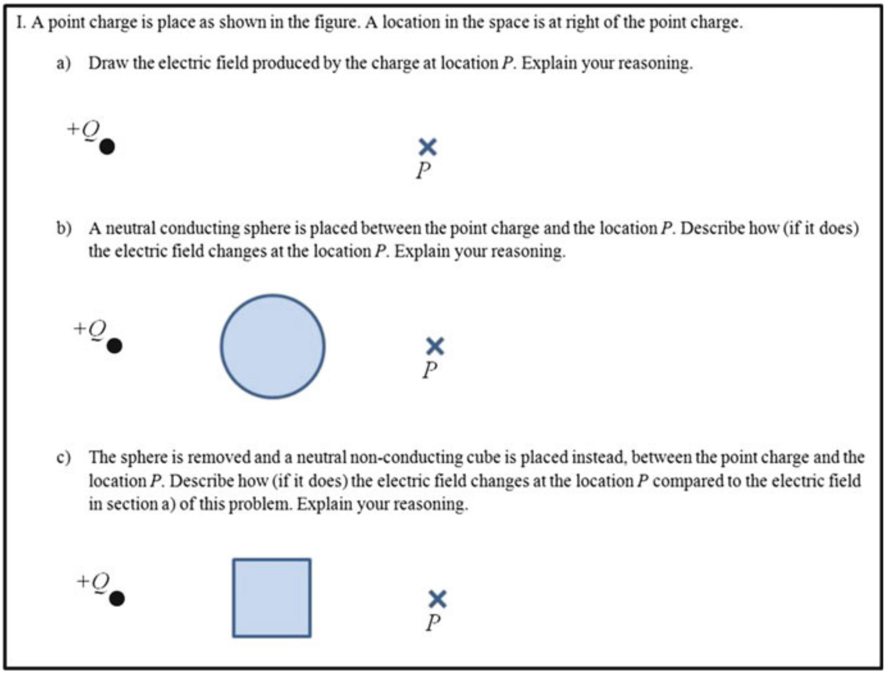


Fig. 11.2 Example of a problem in a midterm exam in an electricity and magnetism course. The problem asks for the electric field when a neutral conductor and a neutral nonconducting material are placed near a charge

answered the first 2 questions correctly but failed to correctly answer the third question.

Some students were able to answer the questions in a very elaborate way showing a complete understanding of the situation. An example of the answer of a student to question (b) is the following:

> The field increases since when we calculate the field by superposition we have the same charge at the same distance. However, there are additional induced charges in the sphere. These charges are identical in amount but positive on the right surface and negative on the left surface of the sphere. However, the positive charge is closer so its electric field at P is greater than the one produced by the negative charge, leaving a net electric field produced by the induced charge as it were a positive charge. The electric field at P would be as E produced by the point charge and E produced by the sphere which the sum is greater than before.

This student drew positive and negative charges on the right and left part of the sphere, respectively along with his answer. His answer is elaborate describing the process of induction of charge in the sphere and how that charge produces an additional source of electric field in the space. He even based his answer explaining explicitly that he uses the superposition principle.

Another less elaborate answer of another student is the following:

> The field increases. The charge polarizes the conducting sphere such that there will be positive charges on the right of the sphere and negative on the left that produce a field at P. By superposition the fields add together.

This student drew positive and negative charges on the right and left part of the sphere and an additional arrow to the right at the location *P* along with his answer.

All correct answers and reasoning for part (b) (22 out of 31) are written similar to an elaborate answer as the first student presented or less elaborate answers as the second student presented. There were seven students who answered correctly that the electric field increases but failed to explain, in a coherent way, why. The remaining two students answered that the field does not change. Their reasoning was similar saying that the electric field passes through the sphere without changing when "arriving" to the location *P*.

Part (c) of the problem (placing a nonconducting object) was harder for students. Ten students answered both questions correctly. One student wrote:

> The field will be less than when the conductor were place and greater than when nothing was there (part a). In this case a polarization is presented in the cube and it will produce a small field at location P adding to the one produced by the point charge in the same direction.

This student drew small dipoles in the cube representing the polarization. There were 12 students who coherently answered part (b) of the problem but failed part (c). From them there were some students who explained that in this case there was no induced charge since charges in nonconducting materials are not free to move. However, there were some other students that talked about polarization but even that, they mentioned that the field did not change.

11.6 Final Comments and Conclusions

We have presented the framework and design of cognitive scaffolding activities that help students to understand the scientific conceptions. The activities can be designed to acquire the scientific-accepted conception or to help students to choose the right conceptions in order to solve problems. They are scaffolding activities since they provide a support for students to achieve academic goals which otherwise would have been difficult to achieve. They are cognitive scaffolding since the activities make students reflect on their own understanding.

The implementation of the activities might be made as introduction to the topic or concept. Then later on that topic, students might work with activities with less scaffolding so that students are being prepared to let them alone during the homework assignments or exams. If an activity is related to a more sophisticated concept or problem-solving, then it can also be implemented not only at the beginning of the topic.

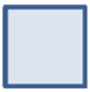
These activities help some students to acquire a robust understanding of scientific-accepted explanations of phenomena. An evidence of understanding was presented in which students answered the exam questions with elaborate reasoning.

A recommendation is to use these activities but monitor the way they are implemented since not all students have difficulties that the activity poses. Although we have some evidence that top students appreciate the activities since they serve them as an opportunity to better organize their own knowledge structure and because some of these students enjoy leading their teams, however, there is also evidence that sometimes they are not as effective for top students since the activity covers topics he/she has already learned (van Merrienboer and Sweller 2005).

Appendix

Section I

The figure shows an isolated neutral conductor cube.



1. Reflect on:
   (a) What an isolated means.
   (b) What it means that the cube is neutral.
   (c) What it means that the cube is a conductor. Elaborate on each answer.

Next to the cube, a location *P* in the space is indicated.

2. Is there an electric field in the location *P*? If so, sketch the electric field and explain your answer. If not, state so explicitly and explain why.

Section II

The figure shows an isolated neutral nonconducting cube with excess positive charge on the left and excess negative charge on the right.

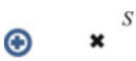
1. Reflect on:
   (a) What it means that the cube is neutral and how that is related to the amount of charge on each side.
   (b) What it means that the cube is a nonconducting. Elaborate on each answer.

   Next to the cube, a location R in the space is indicated.

2. Is there an electric field in the location R? If so, sketch the electric field and explain your answer. If not, state so explicitly and explain why.

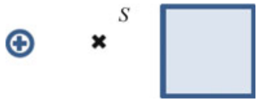
Section III

The figure shows an isolated point positive charge. Next to the charge, a location S in the space is indicated.



1. Sketch the electric field at S and explain your answer.

   A neutral conductor cube is placed next to the point charge as seen in the figure.



2. Electrostatic equilibrium is reached in an instance. What is or are the conditions for reaching the electrostatic equilibrium? Please elaborate.
3. Draw the distribution of the induced charge in the cube. Explain your reasoning.
4. Reflect on whether the cube continues to be neutral or not. If not, explain why. If it does it, see whether that answer is consistent to your charge distribution drawing in question 3 of this section.
5. State the superposition principle for the electric field.
6. Taking into account the superposition principle, answer whether the electric field at location S in question 1 of this section is modified or not compared to the electric field at location S when the neutral conductor was placed. If it is modified, explain how. If it is not, explain why not.
7. Reflect on the electric field produced at S exclusively by the neutral conductor. Describe that electric field at location S.

Section IV

Take your answers to question 2 of Section I and question 7 of Section III.

1. In question 2 of Section I, there was an isolated neutral conductor cube; does this neutral conductor produce an electric field?
2. In question 7 of Section III, there was a neutral conductor cube; does this neutral conductor produce an electric field?
3. Comparing the answers to questions 1 and 2 in this section, how would you respond to the question: is it possible that a neutral conducting object produces an electric field? Explain your reasoning.

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