AC 2010-333: ENCOURAGING CONCEPTUAL CHANGE IN P-12 MEXICAN TEACHERS THROUGH THE USE OF ENGINEERING DESIGN

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Encouraging Conceptual Change in P-12 Mexican Teachers Through the Use of Engineering Design

Abstract

Mexico is suffering from a national crisis in science and math education. At the elementary, middle, and high school level, Mexican students perform poorly on standardized tests in comparison to other developing countries. Additionally, most P-12 Mexican teachers never get the chance to learn about engineering.

In this study, 65 teachers participated in a workshop based on the engineering teaching kit (ETK) called *Save the Penguins*[1, 2] in order to learn about how to enhance science and math learning through the use of engineering design teaching. The *Save the Penguins* ETK is designed to address student alternative conceptions about heat, heat transfer, and temperature, address science standards, increase interest in science and math, and give participants the opportunity to learn more about engineering through the engineering design process.

Mexican P-12 teachers received a condensed version of the ETK, in addition to demonstrations aimed at promoting conceptual change. These demonstrations relied on discrepant events, P-12 teacher prediction, and discussion, and targeted well-researched alternative conceptions about heat transfer possessed by adults. The overall purpose for the demonstrations was to engage the participants in cognitive dissonance and encourage conceptual change. P-12 teachers participated in seven workshop facilitator-led demonstrations about heat transfer. They were designed to provide the scaffolding, which would help the teachers learn scientific concepts, concepts that might be beyond their students' reach when not assisted. After the demonstrations and a brief review of the engineering design process, teachers worked in groups of four, and were required to test materials, then design, build, and test a dwelling that reduces heat transfer in order to keep a penguin-shaped ice cube from melting. The workshop lasted 4 hours and was entirely videotaped; a graduate student took detailed observation notes, and interviewed approximately one third of the teachers, prior, during, and after the intervention. Every interview was recorded and transcribed for qualitative analysis. Quantitative analysis involved statistically analyzing the 10-item multiple-choice pre- and post-test on heat transfer that teachers took prior to starting the workshop and immediately after the ETK was completed.

Results indicate that P-12 teachers made statistically significant ($p < 0.01$) gains in knowledge about heat transfer. Qualitative data analysis corroborated these findings. Previous research indicates that engineering design activities while beneficial for promoting attitudes towards engineering and making science and math learning fun and enjoyable for students, are not sufficient by themselves to promote conceptual change in science understanding. A bridge is needed to connect the design activities with the correct scientific conceptions, and in this study, that bridge has been demonstrated to be these seven well-crafted and research-based demonstrations that allowed P-12 teachers to make substantial gains (obtained a post-test mean score of 6.48 ± 1.54 with an increase of 2.17 out of 10 points) in scientific understanding regarding heat transfer.

Introduction

Mexico is suffering from a national crisis in science and math education. At the elementary, middle, and high school level, Mexican students perform poorly on standardized tests in comparison to other developing countries[3]. Additionally, most P-12 Mexican teachers never get the chance to learn about engineering[4].

Universidad de las Américas Puebla (UDLAP) is a Mexican private institution of higher learning committed to first-class teaching, public service, research and learning in a wide range of academic disciplines including economics, business administration, the physical and social sciences, engineering, humanities, and the arts. UDLAP places a high priority on reaching out to its local community. Such outreach fosters service opportunities so P-12 students can discover science, engineering, and technology careers. Service is a fundamental aspect of being a professional and thus fundamental to our students' education.

UDLAP's *Alimentos Divertidos*[4] is an inquiry-based science and engineering program for P-12 students. We have developed, implemented and evaluated educational materials (simple and inexpensive experiments and ETKs that utilize easy-to-obtain materials) and pedagogical practices designed jointly with P-12 teachers. *Alimentos Divertidos* major goal is to transform how students view, think about, understand, apply and do science and engineering. Among program objectives are to develop, implement, and evaluate: a) educational materials, b) pedagogical practices designed jointly with P-12 school teachers, c) workshops designed to help teachers incorporate the experiments and pedagogical practices, and d) teacher learning communities; as well as to apply and evaluate the use of foods as a tool to facilitate engineering and science learning. *Alimentos Divertidos* can be incorporated to P-12 science classrooms without modifying the existing curriculum at the different types and modalities offered at these levels in Mexico. Our program is fostering that students learn science and engineering DOING science and engineering.

Results to date indicate the importance of placing teachers in the role of "students" and allowing them to experience *hands-on and minds-on inquiry-based activities* as well as grapple with designing their own lesson plans in a peer group setting where they can brainstorm and receive feedback. Therefore annually we hold on-campus one-week summer workshops in order to help P-12 school teachers incorporate the developed experiments, ETKs and pedagogical practices[5]. To further promote the experiments and engineering teaching kits, and encourage implementation of *Alimentos Divertidos* in schools in other states, our faculty has been involved since 2007 in annual workshops at a regional conference in the Mexican state of Quintana Roo[6].

The purpose of this study was to better understand how P-12 Mexican teachers can learn significant science concepts at a deep conceptual level and develop increased interest in and knowledge about engineering through an engineering design challenge that encourages the application of scientific understandings. The research questions guiding the investigation were: i) what are P-12 Mexican teachers' conceptions about thermal energy and heat transfer before, during, and after instruction? and ii) what are ways in which an engineering design challenge changes teachers' conceptions of thermal energy and heat transfer?

Workshop

For over 10 years, professors from UDLAP have been working with the company *Calizas Industriales del Carmen* (CALICA) on a community service project whose main objective is to provide teacher development programs at an annual regional conference (sponsored by CALICA) in the state of Quintana Roo. These programs involve offering for 3 days, distinguished lectures, seminars, and workshops at no cost to teachers in attendance. The program designed for each conference is always different and includes recent educational developments. Workshops offer practical tools to the teachers in order to help them enhance their daily teaching activities, and different areas have been covered including math, history, Spanish, foreign languages, literature, science, engineering, among others[6].

In this study, 65 teachers participated in a workshop based on the ETK called *Save the Penguins*[1, 2] in order to learn about how to enhance science and math learning through the use of engineering design teaching. The *Save the Penguins* ETK is designed to address student alternative conceptions about heat, heat transfer, and temperature, address science standards, increase interest in science and math, and give participants the opportunity to learn more about engineering through the engineering design process[2].

Mexican P-12 teachers received a condensed version of the ETK, in addition to demonstrations aimed at promoting conceptual change. These demonstrations relied on discrepant events, P-12 teacher prediction, and discussion, and targeted well-researched alternative conceptions about heat transfer possessed by adults. The overall purpose for the demonstrations was to engage the participants in cognitive dissonance and encourage conceptual change[1, 2].

P-12 teachers participated in seven workshop facilitator-led demonstrations about heat transfer, four were part of the *Save the Penguins* ETK[1, 2] and three more were tested by our team and are briefly described in Appendix A. They were designed to provide the scaffolding, which would help the teachers learn scientific concepts, concepts that might be beyond their students' reach when not assisted. After the demonstrations and a brief review of the engineering design process, teachers worked in groups of four, and were required to test materials, then design, build, and test a dwelling that reduces heat transfer in order to keep a penguin-shaped ice cube from melting[1] as can be seen in Figures 1 and 2.

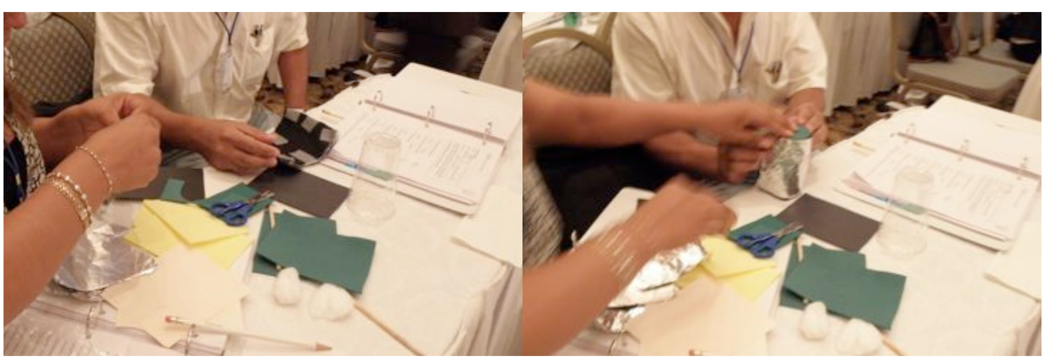

Figure 1. Constructing the ice-penguin dwelling.

As can be seen in Figure 1, using the material provided and after demonstrations and lectures, workshop participants begin to make decisions about designing a structure (dwelling) that will protect the ice-penguin during the final challenge (exposure to radiation, convection and conduction). The ice-penguin dwelling final designs (as exhibited in Figure 2) differed in aspect, shape, form, and color, as well as in cost.

Figure 2. Ice-penguin dwelling final designs.

The workshop lasted 4 hours and was entirely videotaped, a graduate student took detailed observation notes, and interviewed approximately one third of the teachers, prior, during, and after the intervention. Every interview was recorded and transcribed for qualitative analysis. Further information was obtained from an exit survey. Quantitative analysis involved statistically analyzing the 10-item multiple-choice pre- and post-test on heat transfer (Appendix B) that teachers took prior to starting the workshop and immediately after the ETK was completed.

Results and Discussion

Figure 3 presents the school grade in which workshop participants teach, being predominantly elementary and middle school teachers. Female teachers accounted for around 65% of workshop participants. More than 6% of the participants are principals in their schools. Involvement of principals in the workshops is two-fold: first, to raise awareness among them of the possibility of implementing the ETK and demonstrations at their schools, and secondly, several of them also have classroom responsibilities.

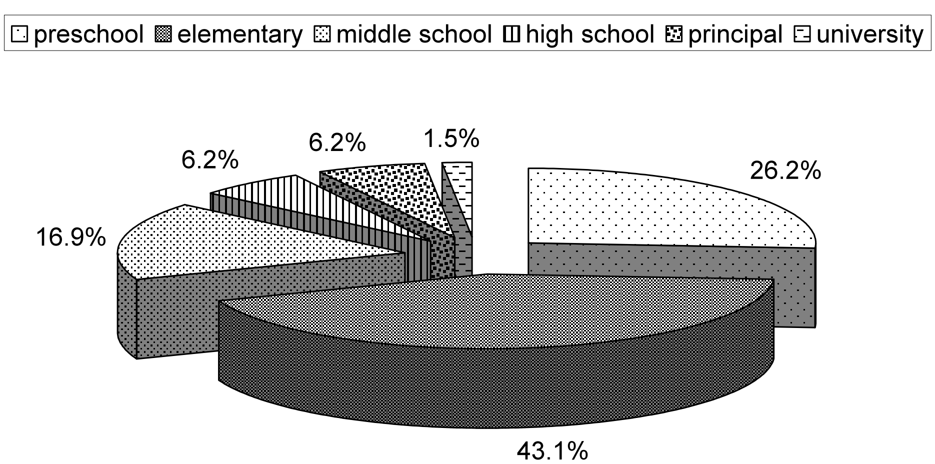

Figure 3. Participants by grade in which they teach.

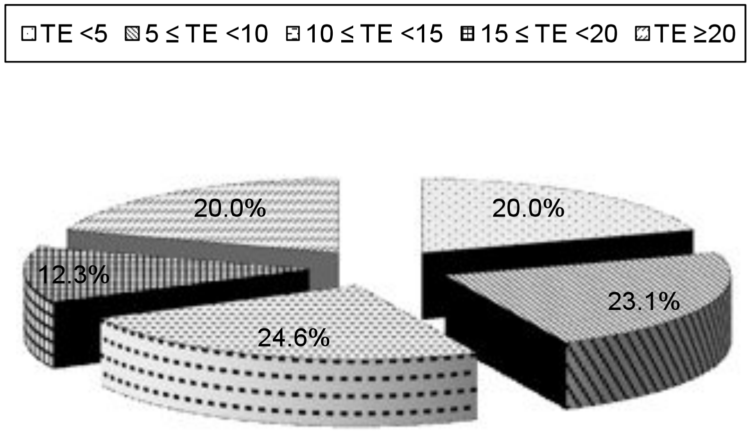

Figure 4. Participants by teaching experience (TE, from less than 5 to more than 20 years).

Figure 4 presents attendee's years of teaching experience; 20% of them have taught for less than 5 years and 20% have over 20 years of teaching experience. Every one of the participants answered the heat transfer questionnaire before and after the workshop. Figure 5 presents the grades obtained. A significant ($p < 0.01$) increase in grades was achieved (a post-test mean score of 6.48±1.54 with an increase of 2.17 out of 10 points).

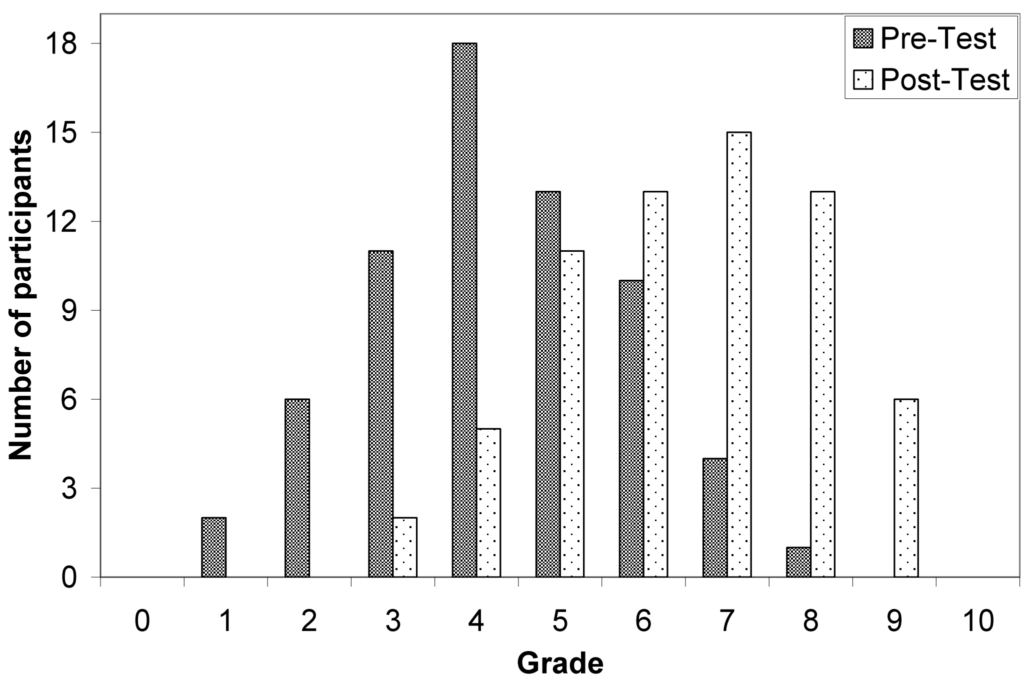

Figure 5. Pre- and post-test scores of the heat transfer questionnaire.

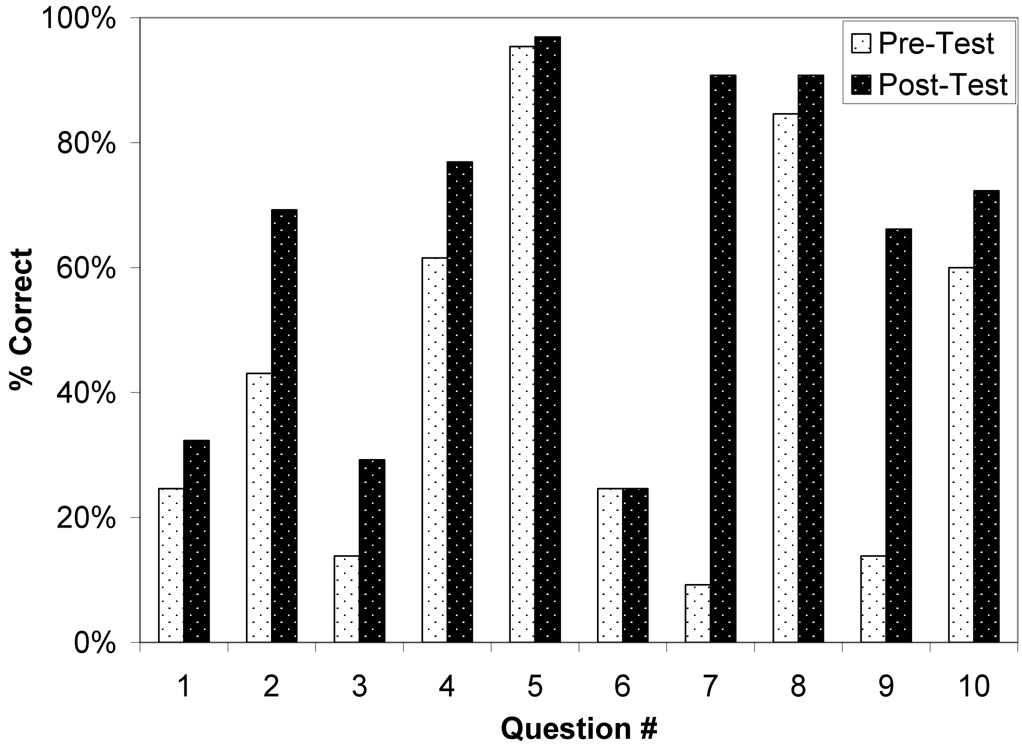

Figure 6. Percentage of correct answers to each question of the heat transfer questionnaire.

For several questions a significant ($p < 0.05$) improvement was observed when answering the questionnaire after the workshop (Figure 6). However, concepts regarding questions 1, 3, and 6 need to be reinforced or the questions altered in order to verify if the concept is correctly addressed with the workshop material, since non-significant ($p > 0.05$) differences were observed in these questions. Particularly for question 6, it seems that incorrect answers could be more differentiated since novices in the field could misinterpret the original ones. The purpose for administering the heat transfer questionnaire was to assess what alternative conceptions teachers had about heat transfer prior to the workshop, and then assess the degree to which learning about heat transfer took place as a result of the workshop[1, 2].

Table 1 presents the responses (they had to grade every question from 1 to 10) of the participants to the workshop exit survey. In general, male participants assigned higher grades than women. Responses to the exit survey indicated that the workshop was successful in preparing teachers and encouraging adoption of the ETK in their classrooms. Many of the responses were encouraging, most participants assigned grades higher than 8.0 to most of the questions.

Results from observation notes and interviews corroborate that most teachers agree that the workshop was interesting and useful. In general, they felt very comfortable performing and teaching using the proposed methodology after the workshop. Participants' reflections during and after the workshop were collected and are summarized in Tables 2 and Box 1. Interviews to gain insights from actual experiences of selected teachers after implementing the workshop ETK in their classrooms will be performed soon.

Table 1. Exit survey results.

	Overall		Male		Female	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
How much you learned during the workshop?	8.63	2.04	9.13	1.13	8.60	2.04
How much fun was to participate in the workshop?	8.86	1.97	9.50	0.76	8.74	2.14
How difficult was the workshop?	2.75	2.79	2.88	3.00	2.80	2.85
How successful was your team´s final design?	8.13	2.13	8.25	1.04	8.08	2.36
Did you enjoyed working in a team?	9.25	1.61	9.63	0.52	9.13	1.76
How engaged were the members of your team?	8.95	1.75	9.25	0.89	8.83	1.89
How well do you understand the concept of heat and how solar energy can be transformed into heat?	8.12	1.95	8.63	1.06	8.00	2.11
How well do you understand convection, conduction, and radiation?	8.12	2.09	8.75	0.71	8.02	2.26
How well do you understand the engineering design process?	7.91	1.78	8.88	0.64	7.78	1.92
Were the instructors of the workshop able to help you learn science through the engineering design process?	9.18	1.03	9.71	0.49	9.11	1.08

Table 2. Reflections from the workshop

Best part of participating in this workshop	*Worst part of participating in this workshop*
Experimenting	Lack of enthusiasm of my team
Analysis	Difficulty of the terms and concepts
Interesting, Entertaining	Lack of time for the challenge
Demonstrations - simple experiments	Answering the questionnaire
Teamwork - discussion, opinion, working together	Difficulty of science and engineering
Transform background concepts	
The contest	
Save the penguins, ecological challenge	
Link between concepts and engineering design	
Learn new teaching strategies	

Box 1. Selected examples of thoughts from participants

- The interaction with other colleagues. Being able to see that there are other ways of teaching, through experiments, demonstrations or innovative activities with simple materials, and how to cover some themes more tangibly
    - *La interacción con otros colegas. Ver que existen otras maneras de enseñar, a través de experimentos, demostraciones o actividades innovadoras con materiales simples y de manera palpable abarcar diferentes materias*
- Realizing how important it is to be creative to make classroom activities with demonstrations and that these can be simple and inexpensively performed
    - *Darme cuenta de lo importante que es ser creativo para hacer clases con demostraciones y lo sencillo y económico que puede ser*
- You shook my cobwebs and remembered my youth years. Although every day we live these situations we rarely question the why?
    - *Me sacudieron mis telarañas y recordé mis años mozos. A pesar de que todos los días vivimos estas situaciones pocas veces nos cuestionamos el ¿por qué?*
- Teamwork dynamics, being able to give opinions for the development of an engineering-based design
    - *La dinámica para el trabajo en equipo, dar opiniones para la elaboración de un diseño tomando a la ingeniería como base*
- The construction of knowledge through experimentation, as well as the exchange of ideas as we worked together in a team
    - *La construcción de conocimiento a través de la experimentación, así como también el intercambio de ideas al trabajar en equipo*
- Face my misconceptions
    - *Enfrentarme a mis errores*

Many children and adults have alternative conceptions about heat, temperature, and heat transfer. The concept of heat as a form of energy evades them[1, 2, 7]. Through cooperative discourse and scaffolding provided by their teacher, this intervention has the potential to help students reformulate their alternative conceptions of heat, temperature, and heat transfer[1].

Implications from this study can inform Mexican P-12 teachers' use of engineering design activities in science classrooms for the purpose of teaching about engineering and also teaching science content at a deep conceptual level[1, 8, 9]. Results may also be of interest to the Department of Education of Mexico in order to develop engineering outreach curricula for P-12 school students[10]. With many states in Mexico trying to start promoting STEM initiatives, the results of this study may help strengthen the results of those efforts.

Final Remarks

Results indicate that P-12 teachers made statistically significant ($p < 0.01$) gains in knowledge about heat transfer. Qualitative data analysis corroborated these findings. Previous research indicates that engineering design activities while beneficial for promoting attitudes towards engineering and making science and math learning fun and enjoyable for students, are not sufficient by themselves to promote conceptual change in science understanding. A bridge is needed to connect the design activities with the correct scientific conceptions, and in this study, that bridge has been demonstrated to be these seven well-crafted and research-based demonstrations that allowed P-12 teachers to make substantial gains (obtained a post-test mean score of 6.48±1.54 with an increase of 2.17 out of 10 points) in scientific understanding regarding heat transfer. The workshop provided participants with opportunities to interact more closely and to develop strong interpersonal relationships, which are widely appreciated aspects of our program and valued highly by the P-12 teachers.

Acknowledgments

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Appendix A

Demonstrations aimed at promoting conceptual change

The greenhouse effect

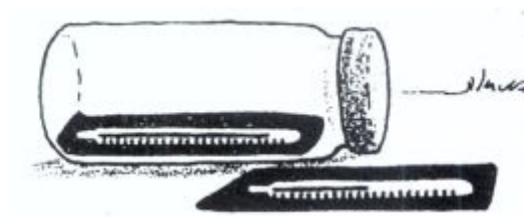
<u>Objective</u>

Measuring the heat energy trapped in a glass container will show us how the greenhouse effect works and can affect humans.

<u>What to do</u>

Prepare two thermometers and make sure that the temperature readings are the same. Find a sunny location (or prepare a lamp). Take one piece of Black paper and place a thermometer on the top of it, then slide (paper and thermometer) into the jar and close it. Put the other thermometer on a Black paper (same as previously) next to the jar. Record both temperatures wait 10-15 min and then record the temperatures again.

<u>Expected results</u>
The thermometer in the closed jar registers a higher temperature than the one outside.



Inflating a balloon upside down

<u>Objective</u>

Air changes its density depending on the temperature. In a closed system and using a flexible material, as a balloon, this effect is seen as the balloon swells inward.

<u>What to do</u>

You will need the following materials: a balloon, a glass bottle with a small mouth (enough to stop the balloon), hot water, a container of ice water, and a container with hot water. Fill the bottle with hot water. Fill the container with water and ice. Quickly empty the bottle with hot water and place the balloon in the mouth of the bottle. As fast as you can, place the bottle with the balloon in the container with cold water and see what happens. Afterwards you can put the bottle with the balloon in a container with hot water and observe again.

Expected results

Water heats the glass of the bottle, which heats the air inside it when it is empty. When the bottle is placed in cold water, the air inside the bottle cools and changes pressure and density causing that the balloon inflates into the bottle. Then when it is put into hot water, the balloon inflates normally.

Hot hands

Objective

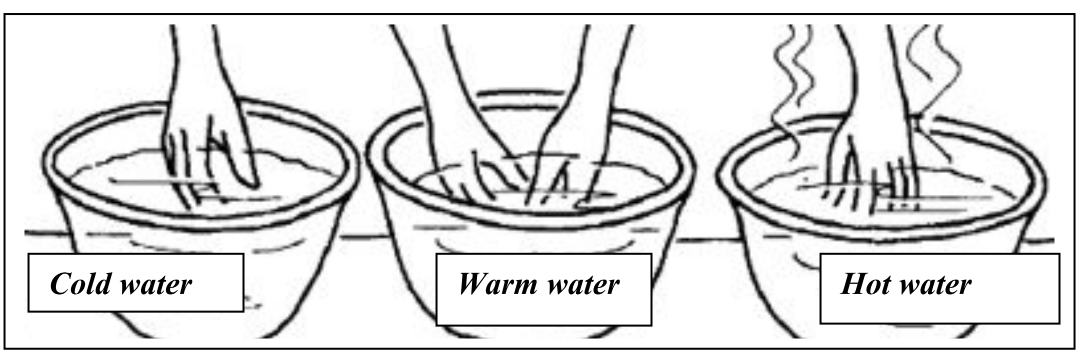
Demonstrate that heat is a form of energy. It is energy that raises the temperature of an object by causing the molecules in that object to move faster.

What to do

Prepare three bowls. Half fill one with hot water. Place warm water in the second. Pour very cold water in the third. Place your left hand in the hot water and your right hand in the cold water. Keep them in for a few minutes. Then take them out, shake off the water, and put both into the middle bowl. How do they feel? You will see that your left hand feels cold and your right hand feels warm.

Expected results

When you put your hands in the center bowl, some heat from your left hand leaves and goes to warm up the water, and so you feel a loss of heat-your left hand feels cold. Heat from the water travels to your cold right hand, and so you feel a gain of heat-your right hand feels warm.



Appendix B

Heat Transfer Questionnaire to Assess Conceptual Understanding (Adapted from Schnittka, 2009[2])

For each question select the answer you consider correct. Be sure to read all the options before selecting one.

1. After cooking an egg in boiling water, you cool the egg by putting it into a bowl of cold water. Which of the following explains the egg's cooling process?
   a. Temperature is transferred from the egg to the water.
   b. Cold moves from the water into the egg.
   c. Energy is transferred from the water to the egg.
   d. Energy is transferred from the egg to the water.

2. Why do we wear sweaters in cold weather?
   a. To keep cold out.
   b. To generate heat.
   c. To reduce heat loss.
   d. All of the above.

3. As water in the freezer turns to ice,
   a. the water absorbs energy from the air in the freezer.
   b. the water absorbs the coldness from the air in the freezer.
   c. the freezer air absorbs heat from the water.
   d. the water neither absorbs nor releases energy

4. On a warm sunny day, you will feel cooler wearing light colored clothes because they
   a. reflect more radiation.
   b. prevent sweating.
   c. are not as heavy as dark clothes.
   d. let more air in.

5. If you put a metal spoon and a wooden spoon into a pot of boiling water, one will become too hot to touch. Why?
   a. Metals conduct heat better than wood.
   b. Wood conducts heat better than metals.
   c. Metals pull in heat because heat is attracted to metals.
   d. Wood isn't as strong as metals.

6. On a hot day, the upstairs rooms in a house are usually hotter than the downstairs rooms. Why?
   a. Cool air is less dense than hot air.
   b. Warm air rises and cool air sinks.
   c. The upstairs rooms are closer to the sun.
   d. Heat rises.

7. You have a can of soda in your lunchbox that you want to keep cold. Which material will work best to keep it cold?
   a. Aluminum foil wrapped around the soda because metals transfer heat energy easily.
   b. A paper towel wrapped around the soda because paper soaks up the moisture.
   c. Wax paper wrapped around the soda because wax paper traps the moisture.
   d. Your wool sweater wrapped around the soda because wool traps air.

8. Why an ice cube melts into water at room temperature?
   a. The ice loses its cold.
   b. Not having a mold the ice cube loses it shape.
   c. The ice absorbs heat from the environment and changes its shape.
   d. Solids respond very strongly to temperature so they melt easily.

9. An aluminum plate and a plastic plate have been in the freezer all night long. When you remove them the next morning,
   a. the plates have the same temperature.
   b. the plastic plate has a higher temperature.
   c. the plastic plate has a lower temperature.
   d. the aluminum plate has a lower temperature.

10. When placed in direct sunlight, which object will absorb the most radiation?
    a. A white sweater
    b. A snowball
    c. Some aluminum foil
    d. A black sweater