ATTACK OF THE ICE ALIENS: A TRANSDISCIPLINARY PHYSICS LESSON

Mel Blake[1], Cynthia Stenger[2], Janet Jenkins[3], Sherry Truitt[4], and Jessica Stovall[2]

[1] Department of Physics and Earth Science,
[2] Department of Mathematics,
[3] Department of Computer Science and Information Systems,
University of North Alabama, Florence, Alabama, USA
[4] Lexington High School, Lauderdale County Schools, Lexington, Alabama, USA

Corresponding author: Mel Blake, E-mail: rmblake@una.edu

ABSTRACT

While a deep understanding of physics is essential, a productive physicist also exhibits mastery of mathematics and computer science. Accordingly, students benefit from instruction that seamlessly integrates multiple disciplinary practices. One body of research holds that the more the investigative problem transcends disciplinary lines, the higher its educational value. This study's curriculum design explores the hypothesis that students engaged in a lesson that transcends disciplines will experience a higher level of learning. The setting of this transdisciplinary lesson is a forensics investigation to determine the time of death of a hypothetical Ice Alien. The assessment was designed to be in the same spirit as the lesson. The research team measured the students pre- and post-ability to think abstractly about the problem and to generalize its solution to other problem situations. Most students showed some indication they had learned to think about the problem at a higher level, some, in general terms, and some were able to encapsulate the general problem situation or process into an abstract object that they then applied to a novel problem situation.

Keywords: Interdisciplinary collaboration, physics education, forensics, python programming, rate of change

---

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 1933677. Special thanks to Kathleen Moon and her forensics class at Deshler High School. With special acknowledgement to Cathy Jones at the Alabama State Department of Education, who encouraged us to expand our Math/CS work to other sciences.

INTRODUCTION

While it is obvious that a physicist possesses a deep understanding of physics, it is also implicitly understood that the successful work of the professional physicist demands a wide range of skills from other disciplines including mathematics and computer science. For example, software needed to solve a given problem may not be available "off the shelf", and the scientist must recognize and recover relevant mathematical equations and write the code that will implement them. Sadly, the trickle down of this logic to schools falls short. Physics, math, and computer science are often encountered in schools as silos of knowledge rather than interwoven, interdependent pursuits. Discipline specific language discourages collaborative efforts, and in fact, students do not recognize a problem that occurs in multiple classes, as it is cloaked in different notation, variables, and terminology. For decades educators and policy makers have seen that an interdisciplinary approach is an efficient, engaging, and productive response to the gap between schools and careers in science. In spite of this, curriculum that fits across disciplines has not widely appeared. This sloth-like response must be remedied to respond to the needs of today's fast-paced, innovative, and highly technological work force.

Motivation for the Project

Interdisciplinary curriculum has occupied curriculum reform documents for years. Early on, it was identified as the number one priority in a curriculum poll administered by the Association for Supervision and Curriculum Development (ASCD). Those polled included Chief State School Officers and deans of schools of education, Jacobs (1989). In fact, it may be helpful to go beyond interdisciplinary, to transdisciplinary curriculum. The idea is that the lessons or curriculum transcend the disciplines involved so that students think in terms of the overall problem situation rather than a specific disciplinary approach. This is not a new curricular idea. Jean Piaget introduced the term transdisciplinary in the early seventies, calling for a unity of knowledge across the disciplines.

Transdisciplinary research has already gained a foothold in the social sciences and humanities and it is making inroads with researchers in science and engineering; Ertas,Tani & Maxwell (2000); Tejedor, Segalas & Rosas-Casals (2017); Stokels, (2006). When seen as a successful framework for educators as well, the hope is that transdisciplinary curriculum will shape future science education and make a way to the synthesis and generation of new intellectual tools and techniques.

Transdisciplinary curriculum is a cooperative undertaking, that originates with a problem outside of or above individual disciplines that calls on individual disciplines for its solutions; Meeth (1978). A helpful metaphor for this approach can be found with the 20th century British philosopher Lionel Elvin. He described the current educational journey as a walk in nature where the hiker spends "three quarters of an hour only with flowers and in the next only with animals (p. 29)". He proposed a more organic approach to the learning adventure where the hiker is immersed in the totality of the forest, Elvin (1977). In her book chapter in *Interdisciplinary Curriculum* (1989), Jacobs (1989) stays in character adding you can still pick up a flower and study it closely, but the difference is that you come to the study of the flower with a perspective about the patch of woods where it originated. This simple organic approach to curriculum development needs a spirit of cooperation among disciplinary experts to compose the forest scape.

The lesson in the present study was developed by a team of two physicists, two mathematicians, two computer scientists, and two high school math and science teachers. Following Meeth (1989), the problem situation was developed outside or above the disciplines of physics, mathematics, or computer science. Care was taken to find common language and notation, so that work could flow seamlessly between the disciplines. The solution ultimately required students to apply tools and techniques from each discipline. This synthesis forms new tools and techniques according to Tejedor,et al (2017).

In the Ice Alien Lesson, true to the imagery in Jacobs(1989), the students encountered physics, math, and computer science integrated "in the wild", but also learned to take up each "flower" for closer examination. Physics was examined in a discussion of the methods of estimating time of death by measuring physical quantities. Math was lifted out of the physical problem and identified as slope and x-intercept. Computer science provided tools to explore the mathematical behaviors and to make predictions in the physical world.

It is hoped that this lesson will inspire school teachers to look for opportunities to engage in a transdisciplinary approach and to partner with colleagues in other disciplines to ensure the material in each discipline is recognizable, so that students start to look for the math in physics class, the physics in computer science class, and so on. This lesson was intentionally developed with this goal in mind.

In order for the students and teachers to be prepared to conduct the investigation, the teacher must discuss the physics, mathematics, and computer science foundations for the lesson, obtain the required equipment, install the Python software, and identify the curriculum standards that are met by the lesson for reporting purposes. Section 2 includes a discussion of preparations and the steps involved in each part of the lesson for the activity and the lesson outcomes, and Section 3 discusses the evaluation of the effectiveness of the Ice Alien activity. Section 4 contains conclusions and future work.

A TRANSDISCIPLINARY LESSON

The setting for this lesson was an Ice Alien crash site. Students were tasked to determine the time of death of four Ice Aliens based upon the amount of ice melt measured at two different points in time (Physics). This provided the student two points in which the rate of change could be determined (Physics, Mathematics). Prior to collecting data in the actual Ice Alien experiment, students wrote computer programs to explore rate of change. The programs allowed students to view time versus volume iteratively (Computer Science). They explored slope, developed time-volume (t,v) ordered pairs, and plotted the ordered pairs using Python graphics (Computer Science, Mathematics). The Python lesson incorporated a discussion of the concepts of slope, y-intercepts, and x-intercepts (Mathematics) and relating them to t-v pairs (Physics). Students recorded their observations and calculated their estimates of times of death of each alien, these were compared to the actual time of death (when the ice started to melt). Error analysis was used to determine the best estimates. The lesson immersed students in the problem, rather than a discipline specific pursuit, e.g., loops or slope, and students experienced the interdependency of Physics, Mathematics, and Computer Science in a seamless environment.

PREPARATIONS FOR THE LESSON

Conceptual Preparations

In order to begin to understand the experiment, the students must first be able to understand the underlying physics of the experiment, in this case, what a phase change is, and the thermodynamics of melting and thus the generation of the water that is used to measure how long the alien has been dead. The teacher should review the states of matter, namely solids, liquids, and gases, and review how differences in temperature affect the rate of melting or boiling of a substance. The teacher may also choose to review, if appropriate, the effect of temperature on the speeds of atoms and molecules.

The Ice Alien project depends upon the thermodynamics of melting. Ice at a given temperature will absorb energy at a rate determined by the ambient temperature, the surface area of the ice, and other factors such as movement of air. When an ice cube melts in air, a thin layer of water forms which insulates the ice and slows the melting. Air currents can evaporate this water, and if humidity is high, the rate of evaporation can be decreased. However, if the environment of the room is held constant, a linear increase in the temperature of the ice is expected up to 0°C, when the phase change from solid to liquid occurs. The energy, Q, to change the temperature of ice by temperature ΔT is given by

$$Q = mc\Delta T$$

Where m is the mass of the ice, c is the specific heat, and ΔT is the change in temperature; Serway and Jewett (2014). At this point, the ice will melt at a constant temperature and turn into a liquid, thus undergoing a phase transition from solid to liquid. To melt the ice completely the energy required is given by

$$Q = mL$$

Where m is the mass and L is the latent heat (Serway & Jewitt 2014). How fast this energy is transferred depends on many factors, including the temperature difference between the room and ice, as discussed above.

If the environmental conditions are held constant, there should be a constant amount of ice melting with time. The plot of the volume of water melted should therefore have a time at the beginning near zero volume while the ice heats to 0°C and for the water to bead to the point where it runs off the ice to be collected. This should be followed by a time of relatively linear increase in the volume of melted ice. We were concerned that Newton's Law of cooling might apply in this situation and would create a non-linear function for the collection of the water and would require calculus to describe to students. This would be beyond the level the students and teachers were prepared for in this lesson. As a result, the experiment described was run at various temperatures and the collection of the water measured and plotted. The result of these experiments was that the water collected initially started slowly, and then became linear. The rates of collection for higher temperatures was greater. As a result, we were satisfied that our simplifying assumption of a linear rate of collection of the water collected was valid. We do not expect the temperature to vary in the classrooms over the time required to run the experiment.

The goal of the Ice Alien project is to push students to move from a low level, basic understanding of linear functions to a more sophisticated, deeper knowledge of its application. Too often, students ask “When will I use this?” truly wanting an understanding of where algebra is used in the real world. Although forensics is not likely to investigate the death of any ice aliens, this project gives students a chance to apply knowledge of linear applications, intercepts, and rate of change to solve a problem in the classroom and experience success. This lesson was prepared for an Algebra II with Trigonometry class. It was used at the midpoint of the Linear Chapter after a thorough review of slope, x-intercepts, y-intercepts, rate of change, and the slope-intercept equation.

Models used in review include algebraic expressions, graphs, and tables. The Ice Alien activity allows students to make a connection to the real world for what rate of change and the x-intercepts and y-intercepts could represent. It further pushes them to expand the linear concepts outside of the x-y coordinate plane to investigate time-volume relations, and other concepts they will encounter in physics, business, and many other applications. Before the experiment, graphs were used to help students conceptualize what a linear graph might represent, as shown in figure 1.

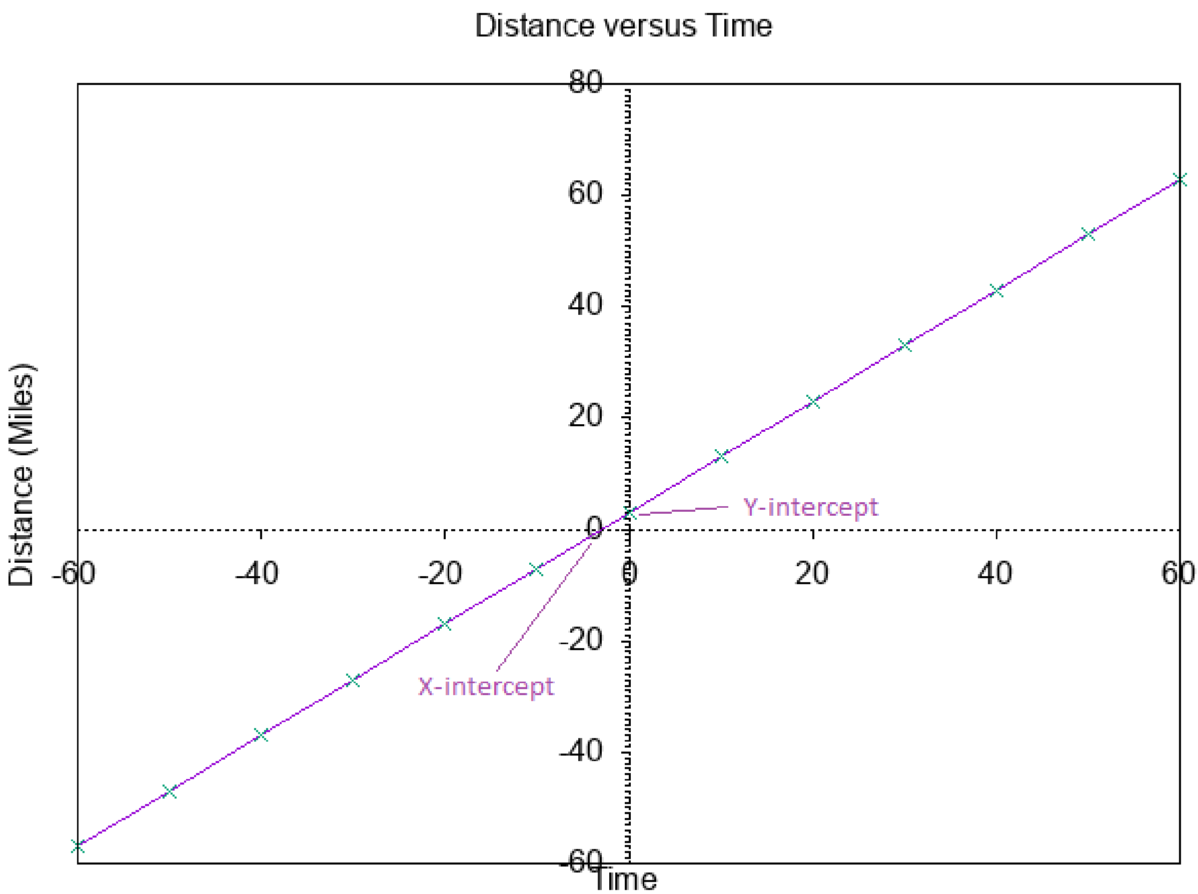


Figure 1. Linear graph with time-distance axes.

Students were questioned about what the x-intercepts and y-intercepts measured and were asked to reason out what the slope represents. Unit analysis was also applied to deepen understanding of rate of change.

To utilize this knowledge, students were given the following scenario with figure 1: "At time = 0, I glance at the odometer and I am 3 miles from home. How fast am I driving, assuming a constant speed? How long ago did I leave home? If it is12:22 pm, what time did I leave?" This discussion led into the physical representations on the graph of the key elements beyond the x-y graphs students are most often exposed to in high school math classes.

Similar scenarios were laid out for discussion such as a bowl of ice cream found on the counter. Given the melting rate, can students figure out how long it has been out of the freezer? These situations give context to the interpretation of negative time, since the question posed is how long ago the event occurred. Often negative time is dismissed. Such examples expand traditional reasoning of linear graphs.

Since the introduction to the Python IDLE environment and introduction to Python Programming takes place as part of the lesson, no computational preparation or review is required prior to the start of the lesson.

Materials and Setup

To conduct this activity, Python should be installed on the machines prior to the start of the lessons. Python 3 is used for the sample code given in this paper. For situations when students have tablets, rather than individual desktops, a web-based Python interpreter may be used. Prior to each lesson, teachers should be sure the selected web-based version has the Turtle library and can draw graphics. The latest download of Python 3 can be found at python.org.

The following materials are required for the Ice Alien experiment for four crash sites

1. 4ea - 4" ring clamp and stand (roughly 20" high)
2. 4ea- 4-6" mouth large plastic funnel
3. 4ea- 250 ml Graduated cylinder
4. 1 set of Tovolo Monsters (Alien) Ice Pop Flexible Silicone Molds (alternately solo cups could be frozen to represent the alien)
5. 1 set of four colors food dye (red, blue, green and yellow)
6. A large bag of small cubed or crushed ice
7. Access to a timer and clock.

The Ice Alien popsicles, or frozen Kool-aide in paper cups, should be frozen the night before the experiment. The four popsicles were in four different colors, so that each crash site station could be identified by its color.

Ninety minutes before students arrived, the stations were set up, with the melting beginning at randomly spaced intervals. The teacher should record the time of each alien's "death". This time is compared with the students' calculated results on Day 4. Aliens were packed with ice to ensure there would be sufficient water volume for the duration of the experiment (figure 2).

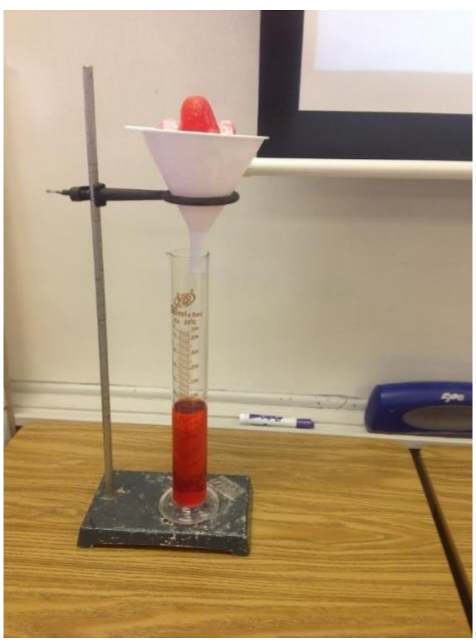


Figure 2. Ice Alien setup.

As the aliens melt, additional ice may need to be added to maintain uniform melting. Students will also need to have access to a timer to record the time at the initial volume reading and the time of the second reading.

DESCRIPTION AND INTERPRETATION OF THE LESSON

The activity can be done in three to four classes, depending on the length of a class period. Since this particular execution of the activity took four days, this paper will describe the activity over four days. We view the activities as a single lesson, given over several class periods, rather than the classes being separate from one another. The first three lectures are designed to introduce the students to the skills that they need to do the final analysis of the time of death of the ice aliens. The first three classes are given as direct instruction, with the instructors going over material and students doing discussion, coding, and mathematical exercises. The final class is inquiry based, and the students are free to solve the problem in teams as they see fit, with instructors there to guide and offer advice and suggestions. Since the ultimate goal is the ice alien investigation, the exercise is ultimately inquiry based. The first class goes over the physics involved in the activity and a brief introduction to Python. The second class focuses on the Python Turtle Graphics package and how to draw lines with ordered pairs, specifically drawing the x- and y- (or t- and v-) axes, generating x and y (t and v) ordered pairs in the printing of a table, and drawing the lines using the ordered pairs generated by the loop in the Python program. Simple linear equations are used to introduce the students to discussing the interpretation of the meaning of slope and the x- (i.e. time) and y- (i.e. volume) intercepts. The third day extends the work from the second day by exploring additional linear functions that have a negative t-intercept. For each equation, the table and graph is output from the program and the mathematical concepts are discussed and explored. The final class is when the Ice Alien experiment is actually conducted. Students collect data, and the time of death is estimated, followed by a review of the activity and discussion of how accurate the results are and what possible improvements might make it more accurate. We discuss the four parts of the lesson here.

Class one: Introduction to Forensics, Introduction to Python

Students should first be given a reminder of how changes in various objects and quantities can be used to determine when events occur. We cover the following principles of forensics in our introductory lesson. A good hunter or tracker can use their knowledge of animal tracks to estimate how long ago an animal passed through a location. Knowledge of the gas mileage of your car can tell you how often you will need to refill on a road trip.

Forensics is the study of dead organisms to determine things such as cause and time of death. Most people have a body temperature of about 37 degrees Celsius. When a person passes away, the body will usually start to cool down to whatever the background temperature happens to be. For a few hours there is little cooling due to bacterial activity, and then after about 3 – 4 hours the body will cool at about 1.5 degrees Celsius per hour for about six hours; Choudhary (web). The cooling then slows to between 0.6 to 1.2 degrees Celsius per hour. This process is called *algor morti;* Choudhary (web). Coroners can determine how long a body has been cooling down by knowing the ambient temperature, the body's actual temperature, and having a set of tables relating the rate of cooling with the body's mass and temperature. Factors such as what the person was wearing and weather are also accounted for Choudhary (web). Plots of temperature versus time are called cooling curves, and can be used to determine the time of death of a body. These are measured in controlled conditions and are very accurate.

In our experiment, a member of an alien race that is made of ice has crashed and been discovered, and the investigators need to use what is known about the melting of ice to determine the time of death. The Ice Alien is placed in a funnel with additional ice and the water is collected in a volumetric flask. The temperature and other conditions of the room are considered unchanged since the time of the crash. As a result, we expect the amount of water being melted to have a fixed rate of change over time. If the investigator measures the amount of water at the beginning of the experiment, and then some time later, then the slope and x-intercept of the curve can be determined using software written by the scientist. This tells the time since the crash took place, and can be used to get the time of the crash.

Once these principles were discussed, a high level introduction of programming and Python was given to the students. The goal is not to teach programming or Python outside of what is needed to explore the mathematics and physics concepts being taught.

In programming, there are three major programming constructs that are often used to assist in problem solving: sequence, selection, and iteration. Sequence is the order in which statements of a program are executed. In Sequence, statements are executed once in a linear fashion. With Selection, some statements are executed based upon some condition with the current state of the program. With Iteration, some statements are repeated based upon some condition with the current state of the program. Students are given the example of an ATM machine. Examples of sequence would be 1. Enter your card, 2. Enter your PIN. Both instructions must happen without condition. Following these instructions, we see an example of sequence. At this point, the usual ATM interface will ask what you want to do next, withdraw from checking, withdraw from savings, check balances, etc. The user will make one selection and the code for that one selection will be executed. At the end of a given transaction, the ATM would prompt the client for another transaction. If yes is chosen, then the menu repeats itself. These constructs are some of the basics of programming.

A computer has 4 basic operations that students must know: input, output, processing, and storage. Input is gathered from a user and brought into storage so processing can occur, then any results to be given to the user is outputted. We began our Python introduction with output. The print statement will print what is in the parentheses, then print a newline after the output. So, to print the number 5, we would use:

```
print(5)
```

We then asked students to print the numbers 1-5 using print statements. They would proceed by doing the following:

Code	Output
`print(1)`	1
`print(2)`	2
`print(3)`	3
`print(4)`	4
`print(5)`	5

We motivated iteration by showing that extending the table to 100 would cause a repeat of the print statement 95 more times. We developed the loop using a flowchart, then introduced the following code to produce the first column of a table:

```
t = 1
while (t< 6):
     print(t)
     t = t + 1
```

We then discussed how t, represents time and starts at 0, increases by one after each print, then stops when it reaches the upper bound. Next, the concept of volume was introduced and represented in the second column as shown below:

Code

```
print("t", "v", sep = "\t")
t = 1
while (t< 6):
     print(t, t, sep = "\t")
     t = t + 1
```

Output

```
t    v
0    0
1    1
2    2
3    3
4    4
5    5
```

Class two: using python to explore graph of a line, slope, x- and y-intercepts

To explore the graph of a line, the slope, and the x- and y-intercepts, students wrote code to build the t,v table representing the ordered pairs that would be graphed. In addition, they used the Python turtle graphics package to draw the equation using the ordered pairs from the table.

The following code was developed with the students to draw the t- and v-axes:

```
import turtle

#DRAW VERTICAL AXIS
turtle.setx(0)
turtle.sety(0)
turtle.goto(0,150)
```

```
turtle.setx(0)
turtle.sety(0)
turtle.goto(0,-150)

#DRAW HORIZONTAL AXIS
turtle.setx(0)
turtle.sety(0)
turtle.goto(150,0)
turtle.setx(0)
turtle.sety(0)
turtle.goto(-150,0)
```

Leaders then guided students through a variety of equations, discussing the slope and the x- and y-intercepts, or more specifically for this project, t- and v-intercepts.

Sample code for exploration of an equation v = 2t:

<u>Code</u>

```
print("t", "v", sep = "\t")
t = 0
while (t< 50):
     print(t, 2* t, sep = "\t")
     turtle.goto(t, 2 * t)
     t = t + 1
```

<u>Output</u>

```
t     v
0     0
1     2
2     4
3     6
4     8
```

The plot produced of the data is a straight line with intercepts at zero (figure 3).

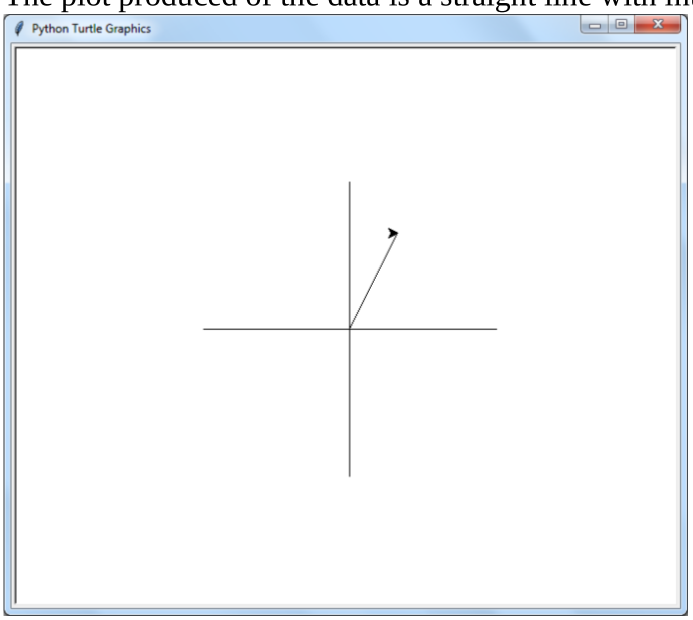


Figure 3. Result of Python code for a straight line with intercepts at (0,0).

Class three: Python Exploration of Line with a negative x-intercept

The next exploration mimicked the function observed for the ice alien, with a negative x-intercept. The sample code for exploration of an equation v = 3t – 16 and its output is:

Code

```
print("t", "v", sep = "\t")
t = -100
while (t< 50):
     print(t, (1/2)* t + 35, sep = "\t")
     turtle.goto(t, (1/2)* t + 35)
     turtle.pendown()
     t = t + 10
```

Output

```
t      v
-100 -15.0
-90  -10.0
-80  -5.0
-70  0.0
-60  5.0
-50  10.0
```

The plot of volume versus time for this equation is shown in figure 4.

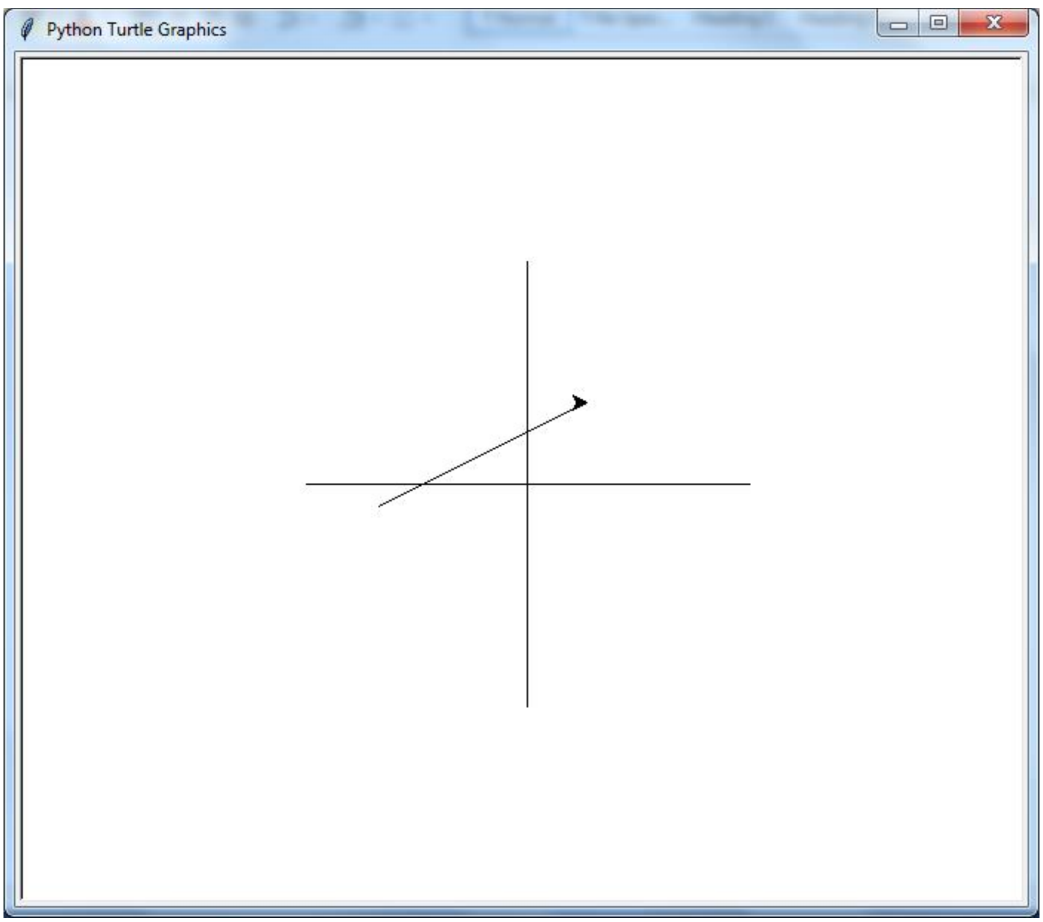
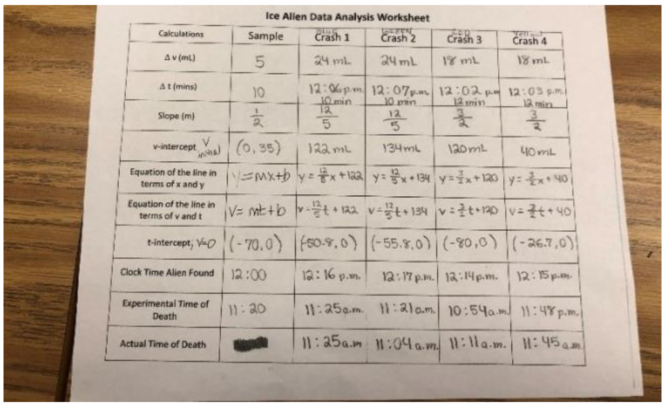


Figure 4. Result of Python code for a straight line with a negative x-intercept.

A mathematical lesson discussing the concepts of slope and negative x-intercepts prepared students for the experiment on the following day.

Class four: The Ice Alien Experiment and Wrap Up

On the day of the Ice Alien experiment, the teacher prepared the crash sites of the aliens as discussed in Section 2.2.1. Students were given data sheets that they used to record their measurements, and determine the time of death of the aliens (figure 5). Each group of students used a graduated cylinder to measure their initial volume of water for each crash site. They then left the room, and different groups measured their initial volume for the crash sites. After all groups made their first measurement, a brief review of the lesson and objectives was done to give time for additional ice to melt. The measuring process was then repeated, giving the students two times and volumes with which, they calculated the time of death of their aliens.



Ice Alien Data Analysis Worksheet

Calculations	Sample	Crash 1	Crash 2	Crash 3	Crash 4
Δv (mL)	5	24 mL	24 mL	18 mL	18 mL
Δt (mins)	10	12:06 p.m. 10 min	12:07 p.m. 10 min	12:02 p.m. 12 min	12:03 p.m. 12 min
Slope (m)	1/2	12/5	12/5	3/2	3/2
v-intercept V(initial)	(0, 35)	122 mL	134 mL	120 mL	40 mL
Equation of the line in terms of x and y	y = mx+b	y = 12/5x + 122	y = 12/5x + 134	y = 3/2x + 120	y = 3/2x + 40
Equation of the line in terms of v and t	V = mt+b	v = 12/5t + 122	v = 12/5t + 134	v = 3/2t + 120	v = 3/2t + 40
t-intercept; V=0	(-70,0)	(-50.8,0)	(-55.8,0)	(-80,0)	(-26.7,0)
Clock Time Alien Found	12:00	12:16 p.m.	12:17 p.m.	12:14 p.m.	12:15 p.m.
Experimental Time of Death	11:20	11:25 a.m.	11:21 a.m.	10:54 a.m.	11:48 p.m.
Actual Time of Death	[redacted]	11:25 a.m.	11:04 a.m.	11:11 a.m.	11:45 a.m.

Figure 5. A completed Ice Alien worksheet.

Students first computed the change in time and change in volume to get the slope or rate of change of the volume of melted aliens, and then determined the equation of the line. This allowed them to obtain the x-intercept (time since the crash), with many running the programs they had developed the day prior to explore the x-intercept. The students were able to use the new equation they discovered from the experiment data and analyze the output of the program. The output of the program allowed them to explore where the line of the equation crossed the x-axis through tabular output (t,v table) and graphically (the graph of the line draw by the program). Knowing the time for the first measurement, they then computed the time of the crash. They were then given the actual time the crash happened and compared it against their value. Experience shows the students can get within a few minutes of the actual time of the crash but can sometimes be off by 30 minutes.

Following the experiment, students reviewed the accuracy of their results, and were invited to discuss ways that the experiment might be improved upon and any factors that they thought might have made their results more or less accurate. The experiment was interpreted in terms of how it relates to forensics, the underlying mathematics, and the application of computer science to the problem.

LESSON OUTCOMES

A key outcome for students in this lesson is the demonstration of how physics, mathematics, and computer science are combined to solve a real-world problem. In addition, the physics of melting and phase changes is reinforced, as well as the mathematical concepts of rate of change and linear equations. The application of computer programs to aid in solving this problem completes the full picture of how physics is done.

EVALUATION

The evaluation plan is based on the goals of the transdisciplinary lesson. Although content growth in physics, mathematics, and computer science was measured in the classroom worksheets, the evaluation plan also measured thinking that transcended the content in the separate disciplines. The APOS evaluation scale measures students' work on a problem in a broader, more general sense. It assesses the extent to which the students' work transcends mimicking the instructor or textbook examples to rise to general or even abstract thinking. Scoring was based on the genetic decomposition that hypothesized what a student learning would look like at the Action, Process, or Object level (details below). This method of evaluation is not the focus of this paper, but the interested reader can find more information in Jackson, Jenkins, Jerkins, Stenger, and Terwilliger, 2020 (cite Exploring the Genetic Decomposition paper).

Assessment Items

The research participants for this study were 11 students from a rural high school in Alabama. We used a pre-test/post-test design to assess the impact of the lesson. The pre-tests were administered, before the lesson. The post-tests were administered the following week. The data from the pre-tests and post-tests was scored on two questions, following the APOS (Action-Process-Object-Schema) scale protocol . The two questions were: (1) Given two ordered pairs (20,0) and (24,5), find the equation of the line between the points and calculate the x-intercept for this line, and (2) A candle is burning and the wax is melting in a pan. Assume the temperature of the room stays constant and the height of the candle at 3 hours and 5 hours is 18 inches and 16.5 inches, respectively. Find the rate of change for the height of the candle with respect to time. Write a general expression for the relationship between the height h of the candle and time t. Predict how tall the candle will be after burning for 8 hours. Explain your answer.

Assessment Scoring

Based on the genetic decomposition developed for this lesson, students were rated according to their level of abstraction over the concept. The ratings were assigned by researchers with experience in the APOS scale and training in the genetic decomposition. The assignments were a ranked set of scores to denote pre-Action (0), Action (1), Process (2), and Object (3) levels based on the genetic decomposition (GD). Each score was recorded for each subjects' submission. Three scorers ranked each participant. In the event that authors disagreed, a discussion and further analysis of the data was used to reach consensus. The scoring protocol followed the principled assessment of student learning described in Snow et al. (2017). Students who demonstrated incorrect or missing conceptual development were assigned a score of 0. For example, a student receiving a pre-Action

(0) score may not have calculated the slope correctly in question 1. Students who answered correctly based on memorizing a formula or referring to other outside sources, were assigned a 1. For example, a student at this level might apply the correct formula for slope and show how they plugged in values. Students who demonstrated they imagined a general process taking place, in their imaginations, were assigned a score of 2. For example, the student at this level might have solved 2b correctly. Since ordered pairs are not given in question 2 and term slope is not given (rate of change), correctly completing 2b indicates they imagine the process in their minds. Finally, students who not only imagined a process, but also encapsulated the process into an abstract entity or object, were placed at the object level and assigned a score of 3. For example, the student at this level might have been able to write a correct general expression for the relationship between the height h of the candle and time t, and use it to predict how tall the candle will be. This demonstrates they could apply their knowledge in a novel problem situation, e.g., they can switch x and y with h and t for the independent and dependent variables. This assessment tool is consistent with the objectives of this study since the student, at the highest level, was able to see the concept apart from or above a particular problem or discipline, and they applied abstract reasoning to find a solution to a novel problem. The students who received the highest scores had moved from applying discipline specific formulas (externally motivated), to imagining a process in their minds and using that process to solve a similar problem in a novel environment (process level). At the highest level, they recognized a general behavior and applied it to the new problem to discover a general solution (object level).

Results of Assessment

Approximately 60 teachers and 100 students have participated in the Ice Alien project. The Ice Alien project was first piloted at a regional high school, then at a summer training session for teachers. From there, the teachers took the project to other regional high schools. One of the teachers has completed the Ice Alien Project in two different school years. For both years, at least one team was within 10 minutes of the time of death for all four aliens and in many instances they were exactly on. The second year the data for the present study was collected. The team results are in table 1 below.

Table 1. Student results.

Alien Station	**Actual Time**	**Closest Student Approximation**	
Red	11:11	11:09	Team 1
Blue	11:25	11:25	Team 2, Team 3
Green	11:04	11:08	Team 4
Yellow	11:45	11:45	Team 3

From the table, the results show that the linear method during melting is an excellent approximation for time of death. The students were thrilled to see that they were able to use the tools of math, computer science, and physics together to produce such accurate results.

The pre-test scores showed that 72.73% of the students were at the pre-action level. The post-test scores showed an improvement, as only 45.45% remained at the pre-action level. The pre-post analysis of the tests show that after the lesson, students had developed a better conceptual understanding of the concept of rate of change. In fact, 45.45% of the students improved by at least one level on the APOS scale.

Figure 6 shows the changes in students' pre-test and post-test scores, and figure 10 shows examples of student work.

Despite the overall improvement in understanding of the role of rate of change in estimating time of death of the ice alien and the demonstrated ability of some students to transfer learning to the candle problem, there was still a significant number of students who remained at the action level of understanding.

CONCLUSIONS AND FUTURE RECOMMENDATIONS

In this lesson, we have designed, implemented, and tested a low-risk introduction of a truly transdisciplinary lesson. This lesson has been implemented seamlessly in a high school forensics class, an algebra II class, and a CS Principles class. The lesson can be implemented in a regular classroom without sophisticated materials, (borrowing beakers, etc.)

Using a common scientific and mathematical language, the lesson exploits the physics problem of estimating time of death using rate of change equations, Python programming, and Turtle graphics to explore the mathematical concepts of slope and x-intercept.

Students engage in two different lab environments, first exploring the mathematics in a computing lab, then taking observations of melting "ice aliens" in a physical lab. Students make two observations, recording time and volume, then use their programs or worksheets to determine the graph of the line that models time as the independent variable and volume as the dependent. Next, they estimate the time of death (x-intercept) and interpret the negative value of the x-intercept as it applies to the lab. Students who developed more than an action level (1) of learning were able to apply the skills from this lab to a similar problem.

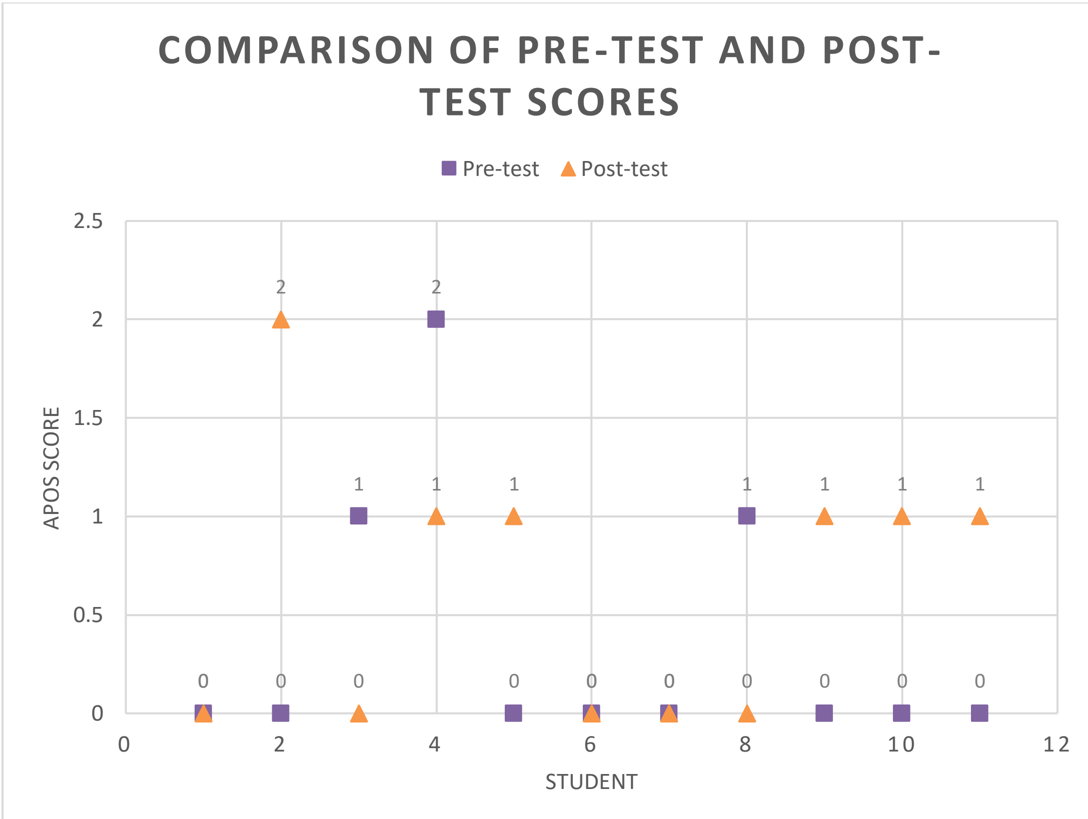
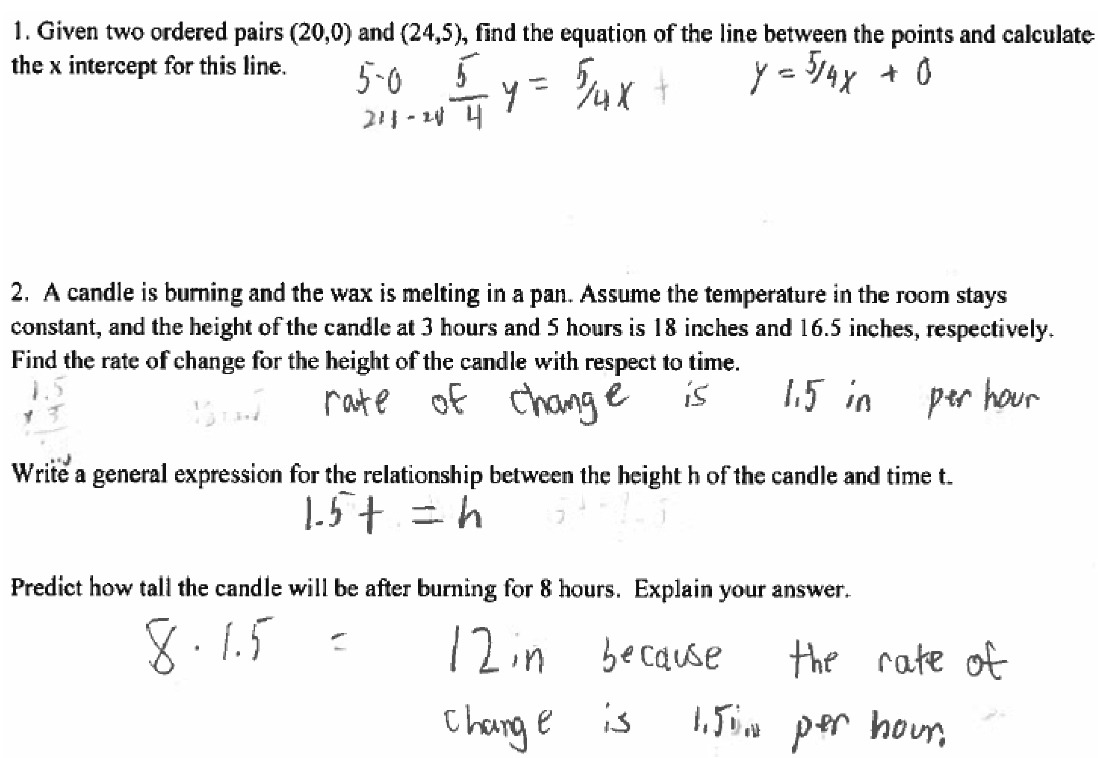


Figure 6. Results of the assessment.



1. Given two ordered pairs (20,0) and (24,5), find the equation of the line between the points and calculate the x intercept for this line.

2. A candle is burning and the wax is melting in a pan. Assume the temperature in the room stays constant, and the height of the candle at 3 hours and 5 hours is 18 inches and 16.5 inches, respectively. Find the rate of change for the height of the candle with respect to time.

Write a general expression for the relationship between the height h of the candle and time t.

Predict how tall the candle will be after burning for 8 hours. Explain your answer.

Figure 10. Examples of student work.

Students who are able to encapsulate the process of melting ice aliens into an object, may be able to solve the candle problem. The object is to use the exploration and iterative nature of the programming to push students to develop deep transfer of learning and to generalize the process of calculating slope and finding x-intercepts, so that it can be applied in a different setting (candle burning). Most students progressed from pre-action to action level, still relying on formulas for slope and x-intercept. One student did demonstrate a process conception.

For future work, additional assessments for the physics and computer science concepts covered should be created and administered.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant No. 1933677. Special thanks to Kathleen Moon and her forensics class at Deshler High School. With special acknowledgement to Cathy Jones at the Alabama State Department of Education, who encouraged us to expand our Math/CS work to other sciences.

REFERENCES

Choudhary, D., "Algor Mortis (Postmorten Cooling), http://www.doctoralerts.com/algor-mortis-postmortem-cooling/

Elvin, L. (1977). *The Place of Common Sense in Educational Thought*. London: Unwin Educational Books.

Ertas, A, Tani, M., Maxwell, T (2000). Transdisciplinary Engineering Education And Research Model. J. Integr. Des. Process Sci. 4, 4 (December 2000), 1-11.

Jacobs, H. H., 1989, Interdisciplinary Curriculum, Design and Implementation.

Change: The Magazine of Higher Learning. Meeth, L.R. (1978). "Interdisciplinary Studies: Integration of Knowledge and Experience." Change 10: 6–9.

Serway, R. A., & Jewett, J. W., 2014 *Physics for Scientists and Engineers,9th Ed.,* Thompson Brooks/Cole.

Snow, E., Rutstein, D., Bienkowski, M., & Xu, Y. 2017. Proceedings of the 2017 ACM Conference on International Computing Education Research. Association for Computing Machinery, New York, NY, USA.

Stokols, D. (2006). Toward a science of transdisciplinary action research. *American Journal of Community Psychology,* 38, 63–77. http://www.springerlink.com/content/46152846475696gu/

Tejedor, G., Segalas, J., Rosas-Casals, M., Transdisciplinarity in higher education for sustainability: How discourses are approached in engineering education. *Journal of Cleaner Production*, 175: 29-37. https://doi.org/10.1016/j.jclepro.2017.11.085