Work-in-Progress: Incorporating Computational Thinking Instruction into K-12 Using 3D Weather

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Abstract

The 3D Weather Analysis and Visualization project (3D Weather) improves middle school students' computational thinking skills. 3D Weather focuses on evaluating three-dimensional data using the full data volume instead of the traditional approach using two-dimensional cross-sectional slices. We use basic meteorology as a contextual framework to introduce and provide the data for the computational thinking exercises. However, instead of directly developing lessons for the classroom, we are using a "teach the teacher" model. We provide a two-week summer professional development for middle school teachers in the state. During the program, the teachers are taught introductory weather science, the IDV visualization software basics, and how to obtain free weather data from the National Oceanic and Atmospheric Administration (NOAA). Restrictions due to the COVID19 pandemic required modifications to our planned initial year activities, but we were able to pilot and obtain feedback to improve the program. Our plans for the 2021-2022 school year include offering our full summer professional development workshop, observing teachers in their classrooms while they implement meteorology lessons with computational thinking, and collecting data from both teachers and students measuring attitudes towards meteorology and computational thinking as well as changes in 3D visualization abilities.

Introduction

Computational thinking can be described as the required thought processes necessary to conceptualize data and create algorithmic steps to solve problems with computers. In 2006, Jeannette Wing loosely defined computational thinking as involving "solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (Wing, 2006, p. 33), and later clarified it as the thought processes used to formulate problems, solve them, and express the solution as instructions that an information processing agent could carry out (Cuny et al., 2010).

However, as computational thinking has matured as a field, numerous other researchers have assessed what computational thinking should or should not be (KaleliOğlu et al., 2016; Selby & Woollard, 2013; Shute et al., 2017). For instance, to Denning and Tiesto, computational thinking is the mental skills and practices that are used to design systems for automation, and explain and interpret the world as information processes (Denning & Tedre, 2019). Meanwhile, Naughton described it as "understanding the difference between human and artificial intelligence, as well as about thinking recursively, being alert to the need for prevention, detection and protection against risks, using abstraction and decomposition when tackling large tasks, and deploying heuristic reasoning, iteration and search to discover solutions to complex problems." (Naughton, 2012). Taking a different tactic, the International Society for Technology in Education and the Computer Science Teachers Association polled teachers, researchers, and practitioners to create an operational definition that lists a set of skills and qualities,

instead of stating an all-encompassing principle (ISTE & CSTA, 2011). Figure 1 shows the results of their inquiry.

Computational thinking (CT) is a problem-solving process that includes (but is not limited to) the following characteristics:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them.
- Logically organizing and analyzing data
- Representing data through abstractions such as models and simulations
- Automating solutions through algorithmic thinking (a series of ordered steps)
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
- Generalizing and transferring this problem solving process to a wide variety of problems

These skills are supported and enhanced by a number of dispositions or attitudes that are essential dimensions of CT. These dispositions or attitudes include:

- Confidence in dealing with complexity
- Persistence in working with difficult problems
- Tolerance for ambiguity
- The ability to deal with open ended problems
- The ability to communicate and work with others to achieve a common goal or solution

Figure 1. Operational Definition of Computational Thinking from the International Society for Technology in Education and the Computer Science Teachers Association (ISTE & CSTA, 2011)

While named for computer science and involving requisite skills for writing programs, computational thinking skills are general enough to be useful for many fields beyond computer science. The Next Generation Science Standards (NGSS) promotes developing computational thinking in K-12 students by integrating the skills into other science instruction contexts. However, there are barriers to implementation. Current in-service K-12 science teachers have not been trained in computational thinking, and there is a lack of tools to help support computational thinking learning. Computational thinking skills are requisite for success in STEM degree programs, especially engineering and computer science; therefore, it is critical that we identify ways to support learning computational thinking skills in K-12 education.

3D Weather Analysis and Visualization (3D Weather) is an NSF-funded project to create a contextual framework around basic meteorology concepts and the display of real weather data for K-12 computational thinking instruction. The focus of the project is on providing the professional development, tools, and support that science teachers need to write lessons that motivate science learning and practice computational thinking. We used weather as our context because, fundamentally,

everyone has experienced weather and been presented with weather information in some form (e.g.., TV weather forecast). The computational thinking skills taught through 3D Weather include:

- Understanding and manipulating complex three-dimensional data through visualization
- Recognizing and explaining patterns (specifically in weather and the atmosphere)
- Systems thinking (in a meterology context)
- Using data to predict outcomes

In particular, we focus on using various isosurface contours and shading to represent three-dimensional shapes instead of the more traditional 2D techniques used for displaying weather information in print or on digital media such as TV or websites.

Is 3D visualization a Computational Thinking skill?

We assert that 3D visualization skills should be included as computational thinking skills, as 3D visualization covers multiple different skills. Some, such as the ability to mentally perform rotations of a three-dimensional object, have been well studied as it relates to STEM disciplines (Neigel et al., 2017; Sorby & Baartmans, 2000). Our work concerns the ability to interpret information within a three-dimensional volume of various types of surfaces with contour and shading. Being able to navigate and work with a 3D data set using 2D techniques and concepts is useful in a wide variety of different fields, including medical imaging (Sun et al., 2008), engineering (Coffey et al., 2012), and archeology (Nuzzo et al., 2002).

There are several reasons why we assert that 3D visualization and the interpretation of surfaces within the data volume qualify as computational thinking skills. A central feature of many definitions of computational thinking, including Wing's (Wing, 2006), is that it relates to solving problems. A critical first step in problem-solving is identifying and scoping the problem, which involves obtaining and understanding the input data. In numerous fields, including engineering, the input data concerns values at points within a physical 3D volume. For this category of problems, the ability to access this information from the computer and interpret it correctly is a critical mental skill that is required to create a solution. Furthermore, some definitions of computational thinking explicitly state that it includes the skills necessary to communicate results to clients (BBC, 2021; K12 Computer Science, n.d.). For engineering, this may mean creating 3D visualization files to illustrate results.

Program

Our goal is to recruit up to 20 secondary school teachers in the state to attend a two-week summer professional development program each year. In addition to lessons in basic meteorology, the science teachers are taught how to download weather data files from National Oceanic and Atmospheric Administration (NOAA) public data servers and how to use an open-source 3D computer visualization tool. During the school year, the teachers are asked to create lessons for their students that teach 3D visualization skills in the context of weather science. As compensation, teachers who participate in the program are offered a stipend and a laptop computer to keep.

While we could have chosen topics from a multitude of fields in which to contextualize the 3D visualization exercises, basic meteorology was the most appropriate for our intended middle school audience. First, unlike some of the fields, the weather is a phenomenon that all target students are

familiar with; they observe and have concrete, physical experiences daily. Everyone has prior conceptions (and misconceptions) about the weather, and we can link to that prior knowledge to help make meaningful learning experiences. Additionally, large amounts of weather visualization data are available from NOAA for free, as the data are public domain and readily accessible. The data includes both current and historical weather data for all regions of the United States and the globe. This former point is essential because it enables our teachers to display local area visualizations to connect to what the students are currently experiencing weather-wise, and to use visualizations of significant weather events that the students hear about in the news.

Since our target teachers span multiple grade levels, it is not practical for us to provide them with lessons and presentations adapted for each possible grade level. Instead, we are using a "teach the teacher" training model; we present the same information to all teachers, and rely on each teacher to create lessons and adapt the material to be appropriate for their students.

The primary content themes and subthemes for the summer program are:

1. Energy and Mass
    a. Temperature
    b. Convection and Vertical Motion
2. Water in the Atmosphere
    a. Atmospheric Moisture
    b. Clouds and Precipitation
3. Distribution and Movement of Air
    a. Pressure and Wind
    b. Global Circulation Patterns
4. Atmospheric Disturbances
    a. Mid-Latitude Cyclones and Fronts
    b. Tropical Cyclones

Every subtopic is split into a series of short lectures, each consisting of 5-6 presentation slides. We expect that teachers will adapt the content and coverage to what is appropriate for their students. While we are initially focused on middle school students and the presentations start from basic concepts, there is enough content depth to be suitable for a high school class. With each unit, we have sample visualizations of weather data that help illustrate the associated concepts. Each visualization file is derived from actual US weather data generated by NOAA.

The primary computer tool we use is the Integrated Data Viewer (IDV), a free, open-source Java software package designed specifically for geoscience visualization. It is available for Windows, MacOS, and Linux platforms and is well established in the meteorology community. Initially released in 2002, it is developed by the Unidata Program Center (UPC)(*Unidata | IDV FAQs*, n.d.), which is a group of institutions that develops and shares tools and data with the Earth Science research and education community. Unidata is primarily funded by the National Science Foundation and is part of the University Corporation for Atmospheric Research (UCAR) (*Unidata Tour*, 2021). Figure 2 is a typical IDV visualization included with the curriculum.
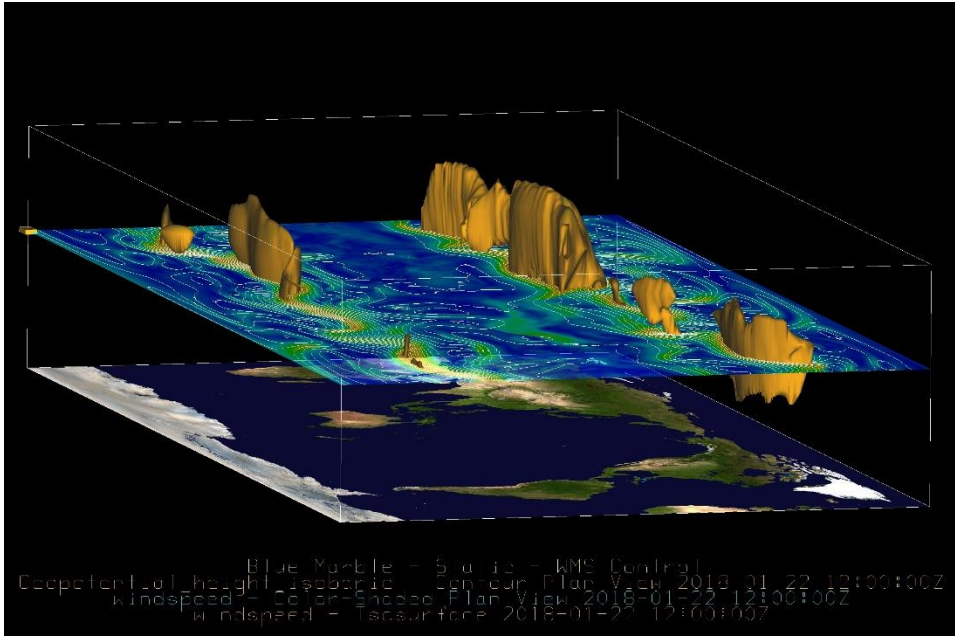
Figure 2. An IDV visualization showing a constant pressure (a.k.a., isobaric) surface colored by wind speed along with surfaces of constant wind (a.k.a., isotach) at a value of 50 m/s. Note the orientation directed from southeast to northwest across the Earth in a geographic projection.

Year 1 and COVID-19 modifications

The first year of the project implementation occurred during 2020. The plan was to conduct the first 2-week summer institute for teacher training during July 2020 and collect data on the teacher implementation of lessons over the 2020-2021 academic year. Unfortunately, the COVID-19 pandemic started in the spring of 2020 and forced us to modify our plans. Due to safety concerns, we shifted the face-to-face summer teacher training to an online model. Lectures on the meteorology content were recorded and used as the audio track over the presentation slides and made available for the teachers asynchronously. Because IDV is a complicated tool, we also held synchronous online sessions to help the teachers install and navigate the software. Due to the increased workload of converting the sessions from face-to-face to online, only two of the four planned content themes were ready for the July 2020 training. From the teachers, we collected some pre- and post-survey data on their attitudes towards computational thinking. The collection of student data scheduled for the 2020-2021 school year was canceled for two reasons. First, since the teachers were under pressure to convert their lessons to remote learning, we did not wish to further burden them with additional requirements. Secondly, due to the difficulties of adjusting to remote learning on the students, it was unlikely that the data that we collected would have been representative of the typical in-person school experience, and thus would have been excluded from our analysis. While we had to scale back our goals for Year 1 considerably, we were able to make use of the time. We treated this year as a pilot and used the feedback we obtained from the teachers to improve the quality of the materials and prepare for Year 2.

Year 2 plans

For summer 2021 and the following academic year, our assumption is that all schools will be back to face-to-face instruction. All four planned content themes are ready for presentation. We will use pre- and post-tests to assess teachers' attitudes towards teaching methods for meteorology and computational thinking. We will also assess whether their 3D visualization abilities improved during the training program. For our "teach the teacher" approach, in summer 2021, we will also provide the teachers with example lessons that individual teachers can modify to create and deliver relevant lessons to their students. The goal for providing example student lessons is to model how one could adapt the professional development material to promote 3D visualization computational thinking skills within the context of atmospheric science. Following the summer training session, we will complete classroom observations of teachers' lessons and pre- and post-tests of students' meteorology knowledge, attitudes towards meteorology and computational thinking, and their 3D visualization ability. If the summer teacher training cannot be face-to-face, we will follow a similar plan as in Year 1, with remote learning for the content material. If the 2021-2022 school year is only offered remotely in our participating school districts, we will either modify or cancel our planned student data collection depending on the conditions at the time.

Conclusion

The 3D Weather Analysis and Visualization project focuses on using 3D visualization of weather data to teach computational thinking with broad applicability and importance for K-12 students. Using basic meteorology as a contextual framework, we have created a curriculum and materials. We are conducting a summer professional development program to train middle school science teachers to write lessons to develop this skill. The software and an extensive repository of visualization data are available for free. While middle school students are our initial target group, there is enough depth to the content material for high school students as well. Despite setbacks in our first year due to COVID19 restrictions, we were able to make use of the time to refine our materials. We are in an excellent position to move forward and are looking towards resuming operations and collecting data on both teachers and students in 2021.

Acknowledgements

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