TEACHING IMAGE PROCESSING IN AN UPPER LEVEL CS UNDERGRADUATE CLASS USING COMPUTATIONAL GUIDED INQUIRY AND POLAR DATA*

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ABSTRACT

This paper describes a method of teaching image processing in a computer science (CS) course in which students obtain and analyze polar data through a computational guided inquiry (CGI) module. In CGI, the instructor guides the students in the process of learning, through the use of a computational tool: for this course, a Jupyter Notebook is used, consisting of alternating text and blocks of Python code that the students can modify as needed and execute. The students obtain images of polar ice and use them to learn about image processing while increasing their climate literacy. Students demonstrated learning of course disciplinary objectives through assessments built into the CGI module. Pre- and post-module surveys indicate increases in student self-reporting of comfort with Python and exposure to polar data. Over half of students indicated increased interest in learning more about polar research, and students overall rated the CGI modules positively. Improvements in climate literacy were tested through asking students to ask a question about a visual representation of polar data; results of this assessment were inconclusive. Future work will focus on strengthening the connection between goals, activities, and assessment, in order to better understand whether the goal of improved climate literacy was achieved.

INTRODUCTION

At a time when decision-makers face difficult decisions regarding how best to respond to anthropogenic climate change, there is a critical need for increased climate literacy in higher education across multiple disciplines. Despite this need, many undergraduate institutions do not currently offer climate change courses. One solution is to include climate-related content in existing courses on other topics; however, instructors in such courses have little leeway or motivation for deviating from disciplinary content. Incorporating climate literacy in undergraduate courses is therefore more likely to succeed if it can be done in a way that simultaneously satisfies existing course learning objectives.

One pathway is to harness the products of polar research. Polar research is intrinsically interdisciplinary in character, encompassing atmospheric science, oceanography, geology, chemistry, physics, economics, and more. The products of polar research, data as well as concepts, are therefore, we hypothesize, readily incorporable into a variety of courses. Hands-on learning with authentic data is best achieved when it takes place within an active-learning environment. In Computational Guided Inquiry (CGI), students learn actively through the use of a computational tool, under the guidance of the instructor. CGI thus has the potential to provide such an environment.

Here we describe development and implementation of a CGI module on image processing, taught in a computer science class. The CGI module described here was developed as part of a broader effort to explore use of CGI to enhance learning outcomes. This collaborative educational project involves faculty from various departments: chemistry, economics, mathematics and computer science. We are guided by the hypothesis that **working directly with polar images via computational guided inquiry can improve undergraduate climate literacy while satisfying or enhancing disciplinary learning outcomes**. In assessing the success of this module, our strategy is to explore impacts on student learning in terms of meeting existing objectives while teaching climate literacy and understanding of polar regions.

CGI module development followed backward design [6], in which curriculum development begins with establishing learning goals, followed by establishing assessment tasks, and ending with design of student activities. Furthermore, the CGI modules were designed with the idea of producing significant student learning experiences. A significant learning experience is characterized as one that engages students, is high energy and results in lasting change in students, provides value to their lives, and helps prepare them for professional fields [2]. Finally, the CGIs use guided inquiry, in which students are guided through an active process of learning through direct engagement with a subject [3]. Guided Inquiry has been shown to improve test scores, growth, and retention, and has been adapted for a variety of settings, such as peer-led guided inquiry [4] and computer-guided inquiry [5].

For the polar image processing CGI module, specific goals include the following:
1. To improve critical thinking and analysis skills through analysis of real data.
2. To increase students' ability to identify problems and motivate them to find solutions.
3. To teach students to use computing tools effectively to solve problems.
4. To train students to become climate-literate citizens with an enhanced awareness of climate change and environmental issues.

METHODOLOGY

The disciplinary goal of the computer science class is image processing. Python was chosen as the main programming language for three reasons: first, since all the students in the computer science class knew Java fairly well, it was expected that they would be able to grasp Python in a very short period of time. Second, because Python is open source and has been widely used in research, many students are interested in learning Python as their second programing language. Third, Python already has an image processing package, and it is beneficial for students to explore the advanced Python packages. Python was taught within the framework of a Jupyter Notebook, a browser-based computational notebook that alternates between blocks of text formatted with markdown and blocks of code. The Jupyter Notebook can be modified and executed by the students in real time.

To motivate learning, background about climate change was introduced through watching short online videos from the National Academy of Science, Engineering, and Medicine, the Royal Society, and National Geographic, as well as videos of change in the Greenland ice sheet over time. After watching the videos, students discussed their observations and reflections. They also discussed what polar research is about and the challenges involved in data collection, as well as the knowledge and skill set required for polar research.

The polar image module was taught in a two-week span in an upper level computer science class: Computer Science Junior Seminar. Each class is composed of 1.5 hours lecture and 1.5 hours lab. Students watched online videos to learn how to install the necessary software on their computers and work through online tutorials to get familiar with Jupyter Notebooks and learn basic Python language syntax and language logics. All these preparations were done during the lab time to spare class activities.

Module and Delivery Method

The CGI module consists of three parts: introduction to polar images and basics of image processing in Python; image repair; and edge detection. Below we describe these in turn, followed by the learning assessment methodology.

To motivate students to learn about image processing techniques, we first introduced polar research. We focused on the impact of global warming on melting of sea ice and the opening of the NorthWest Passage, allowing for a faster shipping route. Students downloaded images of the polar regions taken by NASA instruments on satellites (e.g. worldview.earthdata.nasa.gov). The learning goals for this part include learning how images are stored and represented in Python, how to load, resize (crop), and save an image, how to convert a color image to a black and white image, and how to extract the red, green, and blue components from an image. In interactive class activities, students explored the MODIS website, downloaded their favorite images, loaded them into Jupyter notebooks, displayed them, and explored their composition. Small group discussion and a discovery report provided the opportunity to think and ask questions. Figures. 1 and 2a show examples of images students used. Figures 2 b-d show the red, green and blue layers students extracted and plotted.

To teach students about image repair, we started with an image showing sea ice extent (Figure 3a; [1]; https://nsidc.org/data/seaice_index). The figure was converted to black and white and artificially-created random noise was added to generate the "contaminated" image (Figure 3c). After explaining that contamination consists of unusually large intensity values in a given pixel relative to its neighbors, the median filter algorithm was developed to replace the contaminated pixels with the median values of their neighbors (Figure 3d). The algorithm was implemented during the class interactive session to populate the Jupyter notebook code sections. In addition, a mean filter algorithm was explored to help students understand why mean values should not be used in the image repair, which helped them to refresh their statistics foundations. Another activity was to compare our median filter with Python built-in functions.

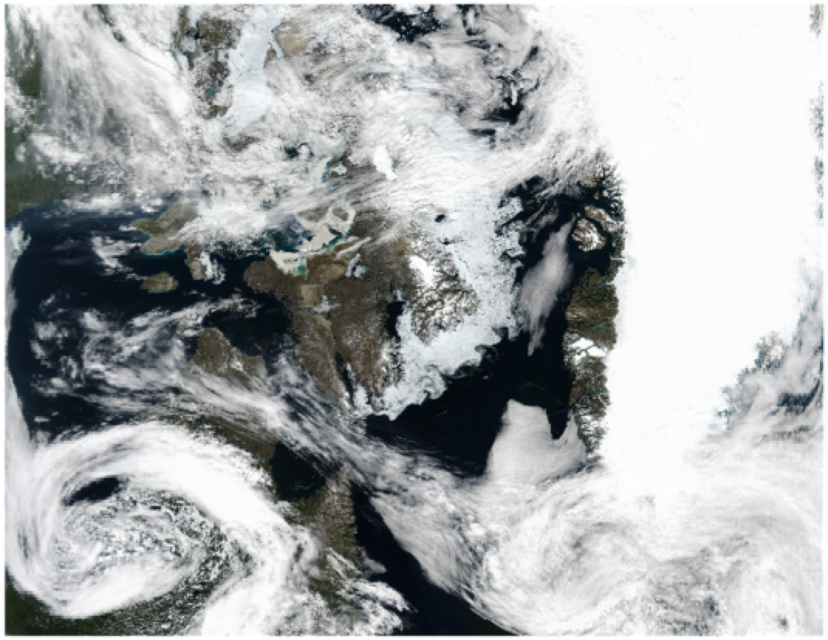

Figure 1: Satellite image of the polar regions downloaded by a student. (Image from LANCE, operated by the NASA/GSFC/ESDIS; see acknowledgements).

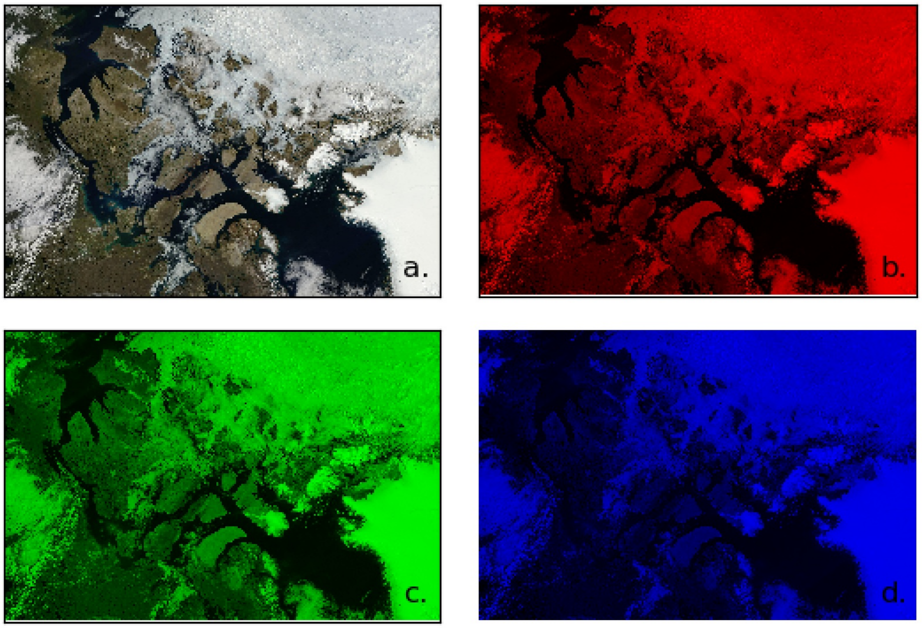

Figure 2: Satellite image of polar regions (a; from LANCE, operated by NASA/GSFC/ESDIS; see acknowledgements) and its decomposition into red (b), green (c), and blue (d) components.

Students used edge detection to determine the sea ice extent. The edge detection algorithm used in the CGI module follows a similar methodology as for image repair. After students learned that the nature of the "edge" is merely a discrepancy among nearby pixels, the class calculated the maximum discrepancy of each pixel and compared it with a pre-set threshold value. The corresponding pixel was marked black if it was greater and white if it was smaller or equal. The resulting image with the edge detected is an image with pixels being either white or black, as seen in Figure 3b. Students also explored scikit-image, the Python built-in image processing package, trying various filters and discussing the pros and cons of each. Additionally, students used a false-color image of the Arctic to distinguish various surface and cloud types.

Assessment of learning outcomes

Student learning outcomes were measured by pre- and post-module surveys. Pre- and post-module surveys were implemented before and after each CGI module to collect student input data. The surveys were developed in collaboration with the Social & Economic Sciences Research Center (SESRC) at Washington State University (WSU), led by Senior Research Manager, Candiya Mann. For the Processing Sea Ice Images Modules, there were 26 total students in the class and there were 14 successful completions of the survey (students who filled the whole survey for both pre and post) yielding 53% completion rate. To assess student learning, the surveys collected the following data on Likert scales: comfort with python programming language, exposure to polar research, importance of polar research, opinions on the relationship between human activity and climate change, exposure to CGI, rating of CGI-Polar modules, suggestions for improving modules, and interest in learning more polar data, as well as demographic information about students. Additionally, students were shown visual representations of polar data that related to the same module and instructed to ask two questions about the visual, but these data have not been fully analyzed and will be reported in a later publication.

RESULTS AND DISCUSSION

Seventeen students completed both the pre-survey and post-survey. The survey assessment was analyzed by the SESRC at WSU. The findings were as follows. All students reported that human activity is significantly contributing to climate change both before and after the survey. Nearly all students reported that polar research is extremely important in the context of climate change (one student responded "don't know" in the pre-survey). Working through the CGI module increased student self-assessment of comfort with the Python programming language. After the CGI module, 11 students reported feeling somewhat or very comfortable with the Python language, compared to 3 before. The CGI module also increased student exposure to polar data from 16 responses of none or a little to 10 responses of some or a fair amount. Five students indicated they would be interested in learning more about polar data, with 10 responses of maybe. Most students rated the CGI module as good (12), with one ranking of excellent.

CONCLUSIONS

Preliminary results indicate that all students believe human activities are contributing significantly to climate change. Students demonstrated learning of course disciplinary objectives through the assessments built in to the CGI module. Pre- and post-module surveys indicated increases in student self-reporting of exposure and comfort with Python, exposure to polar research, and assessment of the importance of polar research. Over half of students indicated increased interest in learning more about polar research, and students overall rated the CGI modules positively.

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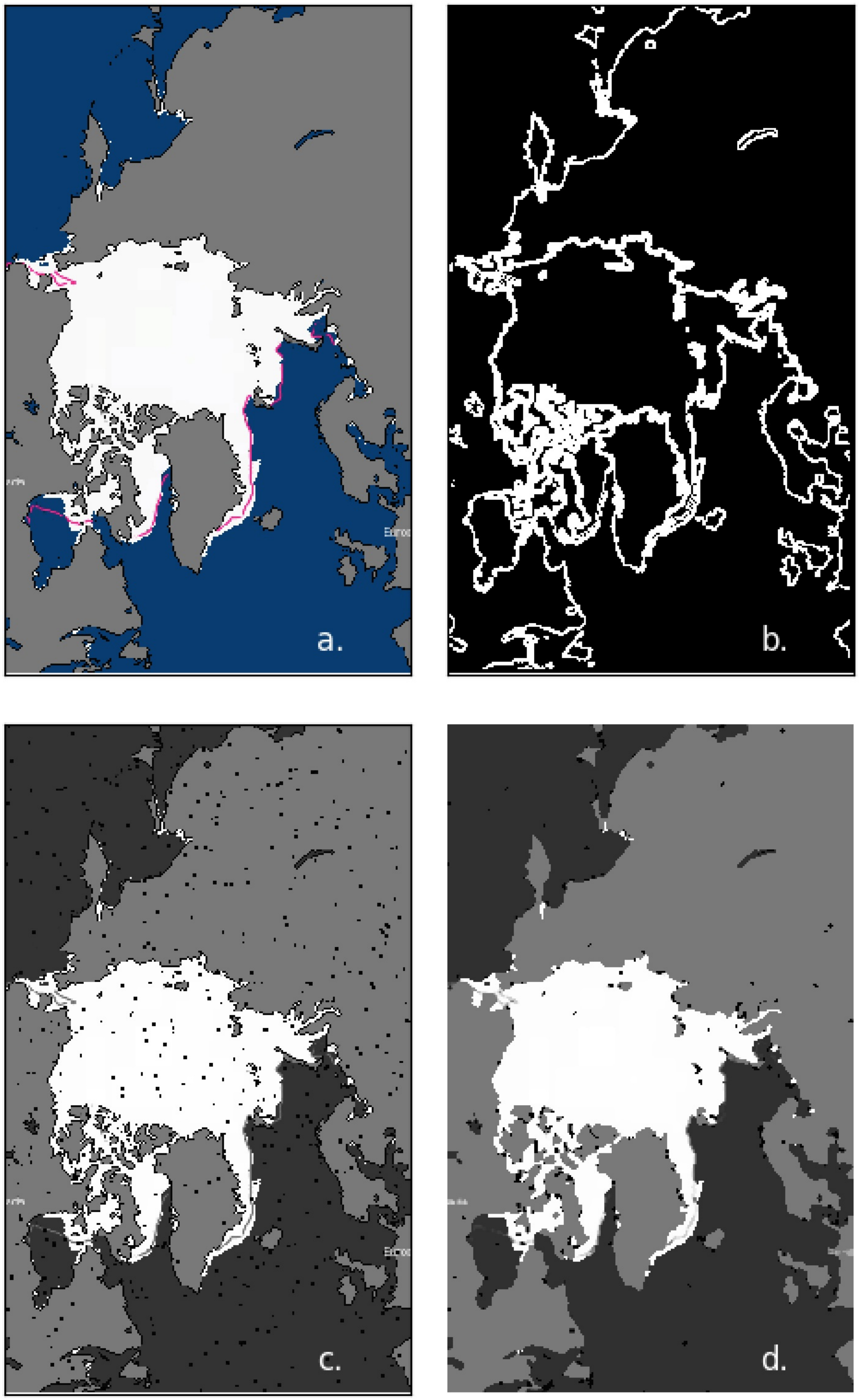

Figure 3: An image showing sea ice extent (a; [1]) as well as images illustrating sea ice edge detection (b), contamination (c), and cleaning with a median filter (d).

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