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Visual storytelling of scientific data: collaborations between physics and graphic design in the college classroom

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Abstract
The Common Problem Pedagogy (CPP) project, a learning initiative implemented in four SUNY schools, aims to provide students with multidisciplinary, project-based experiences, and to foster a culture of such pedagogy among faculty. This work describes one CPP project that was conducted at SUNY Cortland during the Spring 2019 semester that brought together students from physics and graphic design disciplines. The goal of this project was to identify issues of environmental and social concern, develop numerical models to represent the effects of possible policy actions, and to communicate the meaning of this work as infographics suitable for a non-expert, public audience. This article discusses the project structure and organization, the numerical modeling work, the design process and creation of infographics, concluding with reflections on the points of success and plans for further development.

Section 1: Introduction
An important component of a liberal arts education is a curriculum that widens students' capability to understand different perspectives, create connections between disciplines, and form interconnected concepts of the world (Holley, 2009). Many institutions of higher education have embraced project-based pedagogy as a method for encouraging an adaptable problem-solving framework in students, and to deepen their valuation of other ways of thinking and interacting. Such projects often require students to produce work spanning concept development, planning, initiation, and reporting – a broad range of activities that require a diverse skillset. Fink (2013) discussed common pitfalls of traditional learning styles: "Research has shown that [lecture] learning results in most students not being able to recall this information even a short time later" (p.7). Communication is often central to project-based learning, including inter-personal and written communication, both of which are central to a wide range of problems and work spanning the mundane to the highly impactful.

One variation of project-based learning is the multidisciplinary project that requires the formation of a team whose members come from different disciplinary origins. A central feature and learning outcome of this kind of endeavor is the requirement for the individuals within the team to be conscious of differences in training and perspective. Holley (2009) stated:

> [a] key feature of multidisciplinary education is sequence, where similar topics from multiple disciplines are arranged to coincide with each other. In terms of research activities, multidisciplinary endeavors are accomplished through the cooperation of individuals from multiple fields of study who use tools and concepts from their own disciplines applied to a common problem topic (p. 22).

In the case of scientists and graphic designers working together, or more generally members of the STEM and art communities, these differences in training and perspective may require that the scientists learn how to break a problem down into layman terms without sacrificing meaning, and may require that the graphic designers ask the necessary questions to make sure that their interpretations of the models are accurate. On both sides, this process motivates students to take ownership of their projects and leads to greater disciplinary competence.

Four SUNY schools (SUNY Cortland, SUNY Oneonta, SUNY Oswego, and SUNY Plattsburgh) have partnered through an NSF-funded grant for the Common Problem Pedagogy (CPP) project, a problem-based and multidisciplinary framework for collaborative solutions to complex problems (Mattingly and Broyles, 2017). While the immediate beneficiaries of the CPP project are the students enrolled in courses participating in these ventures, the long-term beneficiary of this work are the colleges themselves. The larger goal of this grant is to introduce faculty to the benefits of project-based learning and to establish a culture of multidisciplinary work.

A notable aspect of the CPP philosophy is the “ill-defined” problem wherein students are presented with open-ended goals that have no clear answers, and perhaps not even clear questions. Such problems in the context of higher education are meant to foster a sense of independence and creativity that is both necessary and highly valued for most jobs that imbue an individual with a fair degree of autonomy. According to ICEF Monitor (2016) critical thinking skills, collaborative mindsets, and adaptability are required by today’s rapidly changing economies and labor markets: “Students and employers alike are sending strong signals to educators that the marketplace highly values more varied and multi-dimensional skill sets for graduates" (n.p.). Similarly, Doyle (2011) argued that to optimize student learning, educators should facilitate activities where students are encouraged to debate ideas, work in teams, and create projects that may simulate real-world job assignments.

The CPP project discussed in this paper occurred as a collaboration between physics and graphic design disciplines at SUNY Cortland and involved two courses, Principles of Physics III and Graphic Design II. Connecting science to design has many positive implications, and this project focused on creating a synergy between the two disciplines through creation of infographics. This project was conceived as a simulation of real-world interactions where a design firm was tasked with producing a set of infographics to convey to the public the meaning of a diverse set of scientific studies. The teams of students in these courses researched, modeled, and created visual representations of social and environmental issues which were presented in an exhibition on campus. This work required that students rely on their disciplinary skills since the work was largely partitioned along disciplinary boundaries, but also required them to work cohesively as a team and communicate across disciplines in the sharing of information and ideas. Specifically, this project asked the physics students to develop numerical models of complex phenomena and asked the graphic design students to construct visual narratives from scientific reports without instructor-led guidance as to a correct interpretation.

The subsequent sections describe in greater detail the pedagogical methods of this CPP project including the analysis and creative tasks undertaken by the physics and graphic design students. The paper presents student-created technical reports and infographics, which are discussed in light of the educational goals of this collaboration. The paper concludes with reflections on this collaboration and an outlook to further developments that will be implemented in the next iteration.

Section 2: Project Organization

In this section, we describe the organization of this CPP project: team formation, team communication, timeline, and philosophy of evaluation of student work.

2.1 Team Formation

The pedagogical goal of simulating a professional collaboration motivated the formation of teams composed of mixed groups of physics and graphic design students. Both physics and graphic design students were informed that the end goal of this work was the development of an infographic (size: 17'x 23') to effectively communicate to the general public messages on one of several topics of environmental or social concern. The students were jointly responsible for defining the areas of concern and the specific questions to be studied, while the physics students were mostly responsible for the numerical modeling and the graphic design students were mainly responsible for the development of the infographic. The faculty facilitated progress toward the intermediate and terminal goals through definition of a set of project milestones, while allowing for a large degree of autonomy and shared responsibility among the students.

The optimal size of a group in such collaborative projects is not *a priori* clear. However, contemporary educational studies have shown that accountability is an important aspect of successful group dynamics, implying that smaller groups require greater personal investment of the participants. Furthermore, one of the motivations for group work is to encourage students to communicate with each other, reinforcing the idea that smaller groups will require more significant contributions of the individual team members (Problem-based learning, 2001).

Given the enrollments of the classes (8 physics students and 17 graphic design students), the instructors organized the students into teams of three students composed of two graphic design students and one physics student. Topics were randomly assigned to the teams. Small team sizes were used to promote the four essential elements of a successful collaboration as defined by Mattesich and Monsey (1992): a definition of the relationship; jointly developed structure; mutual accountability; and shared rewards. This CPP project incorporated these elements by providing a structure for the relationship, allowing students to collectively define questions about social and environmental issues, interdependent responsibility of the multiple work components, and full acknowledgement of all contributors in the final exhibition. The faculty facilitated progress toward the goals through definition of a set of project milestones, while allowing for a large degree of autonomy and shared responsibility among the teams.

2.2 Team Communication

One of the limitations of this project was the inability to coordinate synchronous communication between students from the two disciplines since it was not possible to arrange the course meeting times to allow students to meet face-to-face. However, this constraint was incorporated as a feature of the CPP project. It is quite common that scientists and designers may only seldom or perhaps never meet their collaborators or patrons in person, and many professional interactions occur via email, video conference, and other electronic media. Therefore, the requirement for students to communicate via digital communication methods and electronic transfer of documents reinforced the authenticity of this project as a simulation of contemporary collaborations.

SUNY Cortland uses the online course management environment known as Blackboard, which includes gradebooks, document sharing, blogging, and discussion forums, among many other features. This project utilized the Blackboard discussion forums as the primary means of communication between the physics students and the graphic design students. Specifically, a dedicated forum was established for each physics-design collaboration. While only members of each team could post to their forum, all forums were public so that the discussions could be viewed by the other students in the classes in the interests of transparency and the ability to observe the evolution of ideas over time.

2.3 Project Timeline and Actions

Development and implementation of this collaboration occurred over a relatively short timescale of a few months prior to the start of the spring 2019 semester (*see Table 1*). Initial discussions between the faculty members began in November of 2018, wherein it was decided that the Principles of Physics III and Graphic Design II courses would be ideal courses for a CPP project. Final conceptual details were established in December 2018 and presented to the Dean of the College of Arts and Sciences. With some suggestions to broaden the scope, approval to proceed with the project was received in December 2018. Further details of the project goals were refined in a series of conversations starting in mid-January 2019 and extending into the first half of the spring 2019 semester in February and March.

Students were informed on the first day of classes that their course assessment would include a project component. Following formation of the teams, the students were encouraged to introduce themselves to their collaborators and provide additional information about academic and personal interests. The project began in earnest with students in both classes creating individual lists of topical areas they deemed to be of significant social or environmental concern. These covered a wide range of subjects, including such things as student debt, health care, deforestation, the global population crisis. Out of these topical areas, the faculty selected four that were deemed most amenable to numerical modeling: forest management, pollution, world population, and endangered species. Each group then selected one of these four topical areas to focus on, with the constraint that only two groups could work on one topic.

Table 1

CPP Timeline

Date	Task	Constituent
November 18	Initial discussions	Faculty
December 18	Final conceptual details were presented to the Dean of the College of Arts and Sciences	Faculty
February 20	Setting up Blackboard technology	Faculty
March 15	Preference for topical areas due	Design students
March 25	Identification of social or environmental topical areas	Physics & design students
March 29	Definition of four specific questions due	Physics students
April 3	Selection of specific question	Physics & design students
April 5	Development of the numerical model	Physics students
April 12	Design student delegates meeting with physic student team partners	Physics & design students
April 15	Report on numerical model	Physics students
April 21	Data available to design students	Physics & design students
April 22	Begin working with data	Design students
April 22 - May 8	Infographic development	Design students
May 8	Final project due: Common Problem Project presentations	Design students
May 10	Final essay due	Physics students
May 17-August 27	Project Exhibition	Physics & design students

A series of conversations between team members then ensued wherein they refined these high-level, broad topical areas into a specific question around which a numerical model could be built to address a set of actions that could be implemented through public policy. Guidance was given to students to conduct this refinement in a two-stage approach. The first step was general research to identify specific issues under the broad topical area of interest and included activities such as surveying major newspapers for articles related to the topic and reading Wikipedia articles to develop a better sense of the field. This was followed by a second refinement step where a single issue was selected, and each team then developed four specific questions around which focused research could be conducted. Following this process, each physics student met with the physics instructor in a one-on-one meeting to discuss the pros and cons of each question in terms of its potential for numerical modeling. The physics students then shared these findings with their teams and solicited feedback to decide on a single question to pursue.

The main work of the physics students began in the next phase where they translated the specific question identified by each group into a mathematical representation as a set of coupled equations. In subsequent discussions between each physics student and the physics instructor the governing equations and the numerical model were refined. When these details were resolved, each model was run with a set of input parameters that described multiple policy scenarios identified by the teams. The physics students then embarked on their final major contribution to the projects which was a four-page technical report. They then posted these reports to Blackboard and made themselves available for consultation with the graphic design students.

The second phase of the project began with the graphic design students reading and discussing the technical reports. Faculty facilitated a brainstorming session for the graphic design students where both faculty members were present to help students bridge any disciplinary communication gap in understanding the reports. A three-step process of iteration was suggested to the design students to aid in transforming the technical reports into infographics. They first translated the data into socially-relevant information by interpreting the technical reports in their own words and highlighting the important passages, then created a story around the information that could be relayed in a visual format, and the final design process was translation of the story into visual forms. This project concluded with an exhibition held at the end of the semester, titled *Connections*, where the process work and posters from this collaboration were displayed in the physical sciences building at SUNY Cortland. The exhibition featured the finished infographics as well as examples of the process work, large-format displays of the Python scripts used to generate the data, and all technical reports. All team members, physics and graphic design students, were acknowledged in both the finish work and the process work presented at this exhibition.

2.4 Evaluation of Student Work

The students were evaluated according to the standards of their primary discipline. These assessments included components that reflected effectiveness of communication and engagement as a team member.

For the physics students, the overall weighting of the CPP project comprised 20% of the total course grade, which was divided over a participation component (5%), the technical report (10%), and a final reflective essay (5%). To help reduce anxiety about working on a problem that was openly described as "ill-defined" students were informed that they would not be critically assessed for quality of this work, but instead would receive credit based on their effort. The final reflective essay asked students to present three things: (a) a summary of their understanding of their models and the major effects that were observed, (b) a self-reflective description of their thought process as they moved from general concepts to specific questions and on to numerical models, and (c) to offer a brief explanation of how they would begin to develop a model of assessing the economic impact of a change in New York state policy that either encourages or discourages investment in solar energy installations. This last component was in place to provide students with another opportunity to apply their experience in complex-problem solving toward developing a solution strategy for a new problem. The responses to this final, open-ended prompt regarding solar energy policy included ideas and potential solutions outside the range of discourse in this class, which demonstrated that students had applied critical thinking to a new and ill-defined problem.

This project was worth 30% of graphic design student's total final grade. Design students were evaluated based on their ability to successfully demonstrate the following criteria: (a) translate scientific data (quantitative information) into visual forms, (b) design color coded charts, maps, or diagrams, and create a legend and/or use of visual narrative techniques and to tell the story that is embedded in the data to contextualize the social or environmental problem at hand, and finally (c) to communicate and collaborate online in a multidisciplinary environment.

Section 3: Student Work

There were two major products of student work in this CPP project: the technical reports written by the physics students and the infographics created by the graphic design students. Additional works, both written and oral, examined student reflections on the learning process. The following sections describe some of the pedagogical design and finished products from each of these project areas.

3.1 Numerical Models

The pedagogical goal in this phase of the project was to have the physics students consider and then realize how to represent complex systems in mathematical form. It was recognized that most physics students in this course did not have computer programming experience, and therefore writing the code to run the simulations was not a requirement of the students. Instead, the physics instructor wrote the Python script for each model, using the equations and model parameters defined by the physics students as the basis.

The core subject matter of the physics course involved in this project, Principles of Physics III (the third-semester course in the series of three introductory, calculus-based physics courses at SUNY Cortland) concerns waves, optics, and thermodynamics. The connection between these core subjects and issues of social and environmental concern came through a capstone discussion regarding population dynamics at the end of the module on waves and oscillations. Here it was shown that the differential equations describing oscillating strings and pendula share some common traits with the differential equations describing population dynamics.

This discussion progressed through a series of models of increasing complexity, starring with simple exponential growth, moving to resource-limited models, and culminating with a two-group model. In the context of this course the two-group population model was presented in a lecture titled *The Story of the Fish and the Fisherpeople.* The main elements of this model are a human population group that depends almost exclusively on fish for sustenance, and a fish population that regenerates on a timescale much faster than that of the humans and whose population depletes due to fishing in proportion to the number of humans.

A wide range of population dynamics can result from variation of the model parameters, things such as the maximum fish population, the *per capita* consumption rate, and generational periods of the fish and humans. For example, at low consumption rates and high environmental carrying capacity for the fish, the human population grows and achieves equilibrium with a concomitant decrease in the fish population. In contrast, high levels of *per capita* consumption lead to rapid growth of the human population, at some point crossing the threshold of sustainability where over-fishing depletes the fish population and results in extinction, followed by a rapid crash in the human population. The surprise in this model is the existence of intermediate parameter levels where the fish and human populations oscillate out-of-phase in a classical predator-prey relationship (see, for example, Brauer & Castillo-Chavez, 2010, though the literature on this subject is vast and this is not an original source). The oscillations that arise in this last case provides the connection back to the topic of waves and oscillations that is the core content of this course.

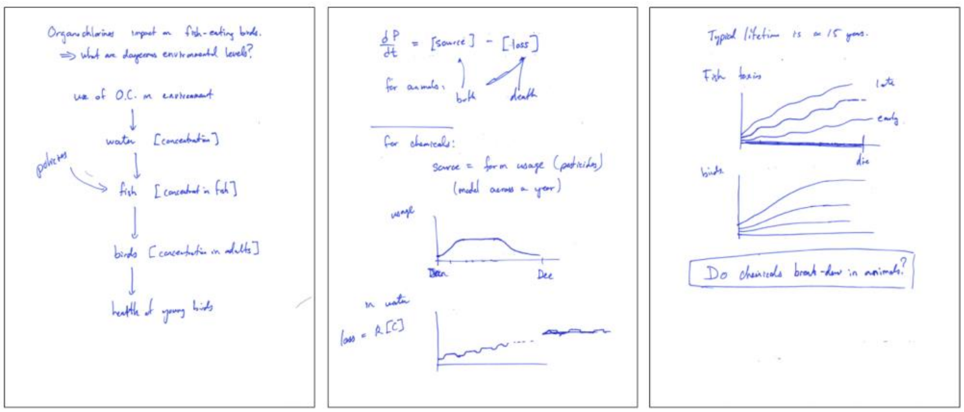

Figure 1. Three pages of concept-development sketches that were generated during discussions between the physics faculty instructor and a physics student regarding the effect of organo-chloride pesticides on raptors. The first page identifies the main steps in the process of pesticide transference from farm to birds, each requiring an equation. The subsequent pages illustrate intuition-based guesses as to what kinds of effects might be seen for different policy actions regarding limitations on pesticide usage.

The discussion of populations can be easily extended to more abstract matters like aquifer depletion or pollutant build-up in the environment by recognizing that these problems are all variations on a theme. Figure 1 shows notes taken during discussions of a model development activity that explored the propagation of a pesticide from a farm to raptors through multiple intermediate steps. The equations describing a chemical in the environment have the same mathematical representation as those of people or fish: a thing increases or decreases in response to internal and external factors. A model of forest growth in western states may be modeled under different possible future climates, some drier and some wetter than the present. The forest population of trees can be modeled as a population of living trees and a population of dead and combustible trees. Growth and death rates of trees both depend on the annual rainfall, and additional death of trees can occur due to forest fires, which have an increased likelihood of occurring when there are a greater number of dead trees, a relationship that generates a self-reinforcing trend of forest loss below some threshold precipitation. Similarly, the model linking pesticide use to raptor populations constructed a set of coupled equations that account for the pollutant concentrations in the ground, in the water, in the fish, and finally the birds. One of the central graphs for the raptor model is presented in Figure 2, which shows how their population might evolve in response to different policy actions.

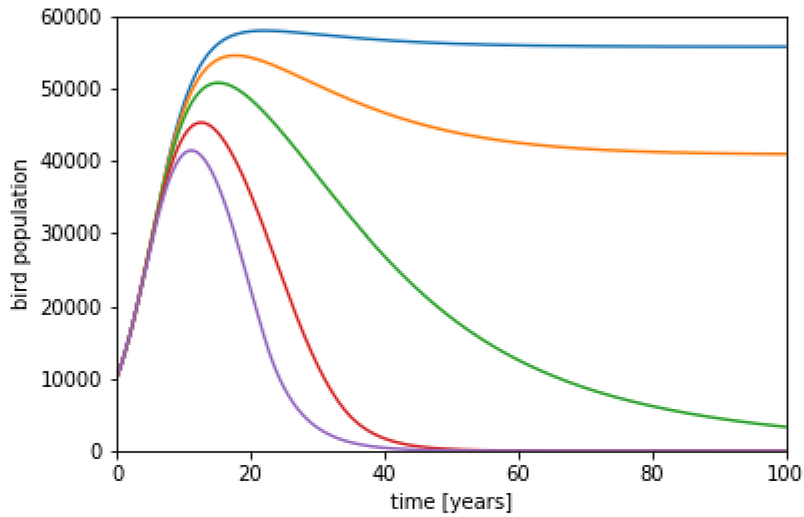

Figure 2. The curves in the graph illustrate the expected raptor population as a function of time, under different policy actions limiting the use of organo-chlorides. The top (blue) curve represents a total ban on use of pesticide where the raptor population is limited by natural environmental causes, progressing to the bottom (purple) curve which represents high pesticide usage and complete extinction of the raptor populations.

Following the development of the numerical models, the students discussed the model parameters with the physics faculty member and refined their objectives. When the model was deemed satisfactory, the physics students embarked on their main contribution to this project which was the writing of technical reports to relay the elements and meaning of the numerical studies to the graphic designers. The only formatting guidelines for these reports were that they explain things in terms appropriate for a non-technically trained reader, and that they contain the following four sections: the question being studied and the policy aspects being explored, a qualitative description of the model including definitions of all significant variables, a presentation of the output data with an interpretation of each graph, and a summary that explained the major findings of the study.

The explicit goal of the technical reports was to present the graphic design students with a complete but accessible presentation of the major findings and limitations of the numerical studies. Along these lines, students were directed to first provide a broad overview of the intentions of the modeling, then get into specific details and provide interpretation of the graphs, concluding with a big-picture interpretation of the meaning and limitations of the study. The following is an extract from the introduction of the technical report written by a physics student on the subject of the response of a population of birds-of-prey to use of a specific pesticide:

> This project focuses on the effects of organo-chlorides on fish-eating birds, and more specifically, the amount of organo-chlorides that could be consumed before reaching a dangerous level. Organo-chlorides are common in pesticides, insecticides, and insulators. When water runoff from farms and businesses goes into streams and lakes it gets absorbed by the fish and is held in body tissues or organs. Most fish can withstand an incredible amount of toxins, but the birds that prey on them cannot. When too many toxins are consumed the birds' eggs are thinned, causing them to break and their population to decrease.

Perhaps the most interesting result of this study is represented by the second curve from the top (orange) in Figure 2 which illustrates an important point: there exist intermediate levels of pesticide use where a healthy raptor population can be sustained while also offering some benefit to farmers. The student working on the raptor project commented on exactly this point:

> With this data, there are two opposing views that the information can be involved in. There's an environmentalist standpoint, which concerns the amount of birds that are dying from unnatural causes...To help fix this situation would be to control the runoff of the organo-chlorides and ensure none entered any natural water source, or to create a pesticide that will be non-toxic to the birds. The latter would be much harder to accomplish, so the most realistic solution would be to create a way to dispose of the runoff, or to limit the amount of pesticide usage, so although it would still have effects, they would be much smaller...However, limiting the use of pesticides would affect farmers greatly. By limiting their use, it would be most likely that less of their crops would survive, giving them less money and putting them in more of an economic hardship.

The above passage is important because it shows that the student grappled with complex ideas and honestly reported that the science does not indicate a correct answer because it is agnostic as to whose interests are more important. The meaning that is becoming apparent to the student is that science cannot itself support a single policy perspective because such statements do not answer the hidden question of: which of the competing interests is more important? Such questions require much larger thinking and often involve consideration of a wide array of economic, environmental, cultural, or social factors that exist outside of the science. Therefore, the work of communicating to the public a particular message is often beyond the scope of scientific studies and falls to science communicators, designers, politicians, and others to offer a lens for interpretation.

3.2 Infographics

This project focused on creating a synergy between art and science. Connecting art with science has many practical implications, one such example being infographics. Steele and Iliinsky (2011) defined infographic as" [v]isualizations that are manually generated around specific data, tend to be data-shallow, and are often aesthetically rich" (p. ix). By creating infographics, graphic design students learn how to interpret scientific data and to convey the message from a scientific environment to a more general target audience. The goal of this process is to transform data, though a multi-leveled process of interpretation and concept development, into readily-usable information. Only after this process results in a mature understanding do the designers embark on creating imagery of their visual designs.

Another step before visually representing the data is to create a story from the technical report. The graphic design instructor introduced students to a multitude of design techniques such as the visual narrative technique and infographics. Next, the instructor guided students to build a story, one way which was suggested to students was to first define the protagonist and antagonist of the plot, and then identify the time and space where the story takes place. Next, students addressed the question *what is at risk,* which may suggest a call to action. This allows the viewer to connect emotionally to the visual message, which brings an additional motivational aspect to the story. The instructor encouraged students to use the principles of design, such as compositional tension, and color contrast to drive the action forward. Design students then constructed the visual representation of the story, considering typography, layout, color tone, and the narrative techniques, with a goal of evoking the desired emotional response from the audience.

Figure 3 shows a project that had a goal of convincing the viewer of the connection between two different measurable phenomena, in this case wealth and birth rate. This poster used color-coded charts, maps, and diagrams to help the audience interpret this information. Figure 4 showcases an example of a student project, using the visual narrative technique, that tells a story of the consequence of overuse of agricultural pesticides. This student team used many design principles, such as the Gestalt theory and movement. This dynamic drives the viewers' eyes from point to point on the page and connect the visual sequences. Figure 5 is an example of a student project that used compositional tension to represent the polluted environment world, and the second part of the composition depicts a sustainable world. The contrasting sides of the composition creates tension which intends to evoke emotional reactions from the viewer and encourages the audience to take action.

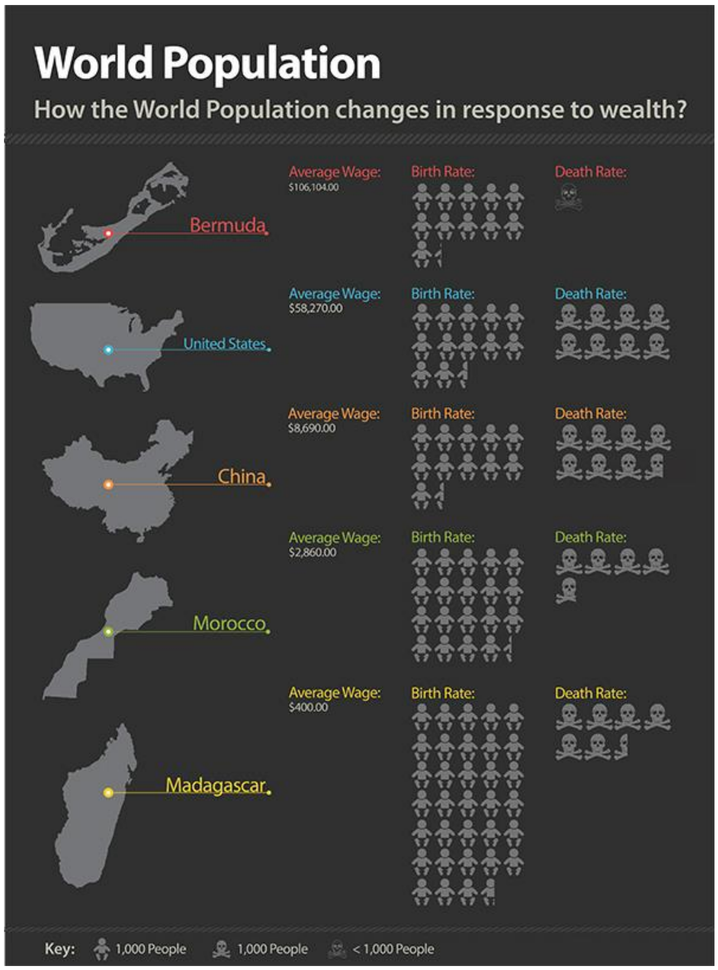

Figure 3. This poster depicts the correlation between wage and population growth in some representative countries. This student-group designed maps and symbols to create an easy-to-understand infographic to inform and educate the general public about how wealth might be connected to birth and death rates.

Figure 4. This work a visual design using the technique of visual storytelling and is a response to the technical report on the subject of the effects of pesticides on raptor populations. By using the visual narrative technique along with the principles of design, students created a time-based narrative that answers the "who, when, and where" questions. The infographic also offered a solution to the problem.

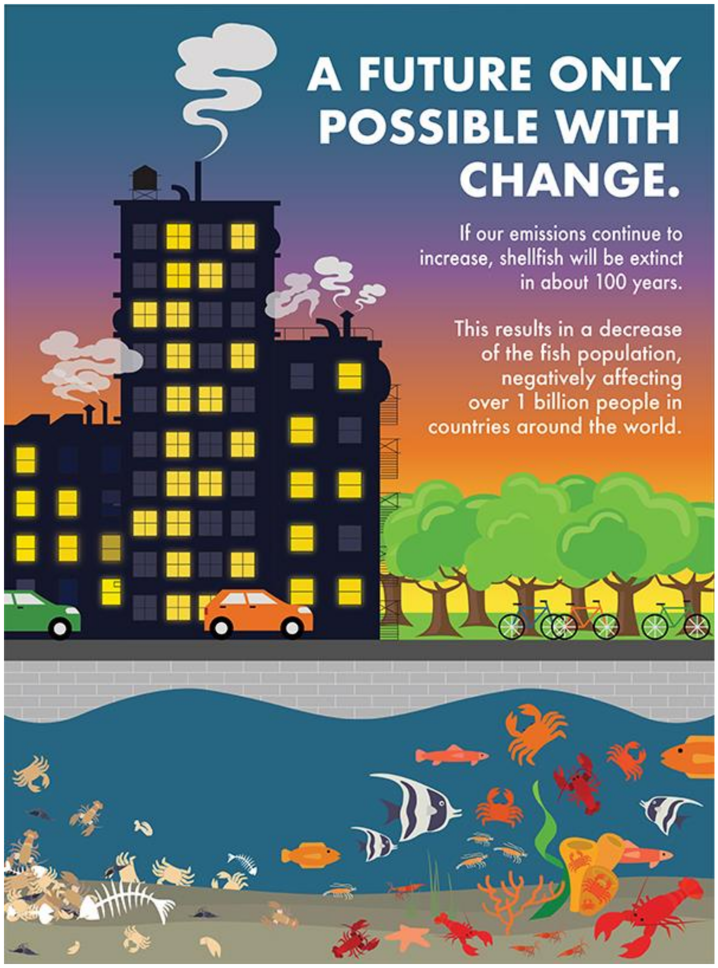

Figure 5. This project juxtaposes two contrasting future possibilities: on the left side of the composition, a polluted environment, and on the right a sustainable future. These two opposite scenes require the viewer to make a decision. The poster brings awareness and calls for action to save shellfish population from extinction by an appeal to environmental consciousness.

3.3 Student Reflections

At the conclusion of the project students shared some of the opportunities and challenges they encountered during their work on the CPP project. Overall, students expressed an eagerness to work on the CPP project. The final, reflective essays of the physics students showed a general willingness to wager responses to novel and difficult problems, and an appreciation for the value of the ill-defined and multidisciplinary aspects of the project:

> From the research perspective, I thought that this project was very beneficial. So far in this major, it's a lot of equations that deal with situation problems, but we are given the numbers and equations. This project made us start from scratch, which showed me a little more about the possibilities of what I could be doing in this field of work. I liked how we had to think about it conceptually and use our knowledge of trends to think of it numerically.

This student also commented on the socially-conscious attributes of the project:

> It also opened my eyes to how politics and other recent social issues contributes to this field of work. We could look at almost any controversial issue and create an equation and a trend graph for it.

Another physics student spoke to this evolution of his understanding about the goals of the project. At a superficial level this could be interpreted as a realization of what was expected, but the deeper lesson that is expressed here is an understanding that rough estimates (or models) can be useful places to start to build intuition:

> At first, I was intimidated by the research I had to do because I thought I needed to get lot of information on actual numbers and statistics on the future outlook of forests in the west. I did not know it was more or less a rough estimate to help us build our own model. Once I knew I didn't have to do heavy extensive research I was less overwhelmed by the project.

This student described the perceived benefits of the multidisciplinary project in commenting that it felt more realistic than other work:

> It was a fun and interesting process that gave me a peek into what real world jobs for scientists are like, working with numbers and translating them to designers to help convey a message to the public. I think it is a great idea for classes to incorporate into their curriculum to help student get a step ahead when entering the work force.

The multidisciplinary and simulated professional experience was echoed in the feedback of many graphic design students as well. One graphic design student noted:

> The common problem project was a difficult but rewarding experience. It is difficult because it takes a lot of communication across a lot of people, as it would work in the work force as well.

Many students reported that the multidisciplinary teamwork helped them appreciate the creative process of brainstorming and making collective design decisions. Along these lines, one graphic design student elaborated on her experience working in in team:

> For the Common Problem Project, our group had to choose a problem for the Physics students to collect data on. Once we received the data, my team and I had to brainstorm how to present the information visually... After contemplating different formats and concepts, we landed on a common ground and started sketching out rough drafts. During this phase, any problems or questions that came up were tackled by the whole team, coming up with ideas to resolve them.... with good communication, and having our own individual strengths and weaknesses, we were able to create a project that strongly depicted the information.

Faculty encouraged students to continually challenge their ideas and perspectives and to embrace the act of revision. One of the major points of discussion, for both physics and graphic design students, was the need for an iterative process of creation, where work is assessed and revised. A graphic design student commented on the process of refining her work:

> There was a lot of information to work with and we chose the affect of the problem to be the main point... The first concept we had was to display it in quadrants, but the placement looked weird and made the birds appear under water. With our final layout, we considered making it a full poster that connected instead of separating them in boxes.

Many student comments indicate that they may have felt overwhelmed with the complexity of the assignment initially, but ultimately came to appreciate the applied learning and multidisciplinary component of the CPP project. They also often commented that the work improved their core disciplinary skills and lead them to realize how another discipline could dovetail directly into their work.

Section 4: Conclusions and Further Development

Ambrose (2017) explained that “[L]earning is a process, not a product. However, because this process takes place in the mind, we can only infer that it has occurred from students’ products or performances” (p. 3). The major manifestations of this CPP project were the technical reports and infographics, objects whose express purpose was the communication of complex ideas, and provided a measure of learning through the thoughts that were captured there. However, woven throughout these projects were numerous conversations which, in the perspective of Ambrose, can be interpreted as spontaneous performances through which we can also observe learning.

While students, faculty, and external reviewers generally agreed that this CPP project added significant value to the student experience, the faculty instructors also believe that there is substantial room for improvement. The technical reports and infographics were, by themselves, considered to be of generally high quality and showed that students successfully applied disciplinary thinking, and also effectively communicated across disciplinary boundaries. However, despite these successes, the faculty instructors believe that this project only scratched the surface of such interactions and that more could be done to create a deeper sense of shared responsibility. The main goal of changes to the project structure that the instructors foresee implementing in future iterations is to encourage more conversation between students across the physics-design boundary.

One simple way this can be done is to hold an initial discussion on the philosophy and methods of project management, and then to give students a large degree of autonomy and self-governance of their teams, guided by a set of major project milestones and dates. Such inter-dependence could be fostered by introducing the physics and graphic design students to each other earlier in the semester and building a stronger relationship through a series of low-stakes, joint assignments that involve research and debate. Alternatively, while it seems obvious that the physics students should focus on the numerical modeling and the design students on the infographic creation, this need not be stated explicitly and could be left for the students to define. Following the major advances of ideas, but prior to embarking on the primary physics and design creative activities, more could be done to encourage the physics students to seek explicit approval from the design students regarding the concept of the numerical modeling, and in turn to have the design students seek the approval of the physics students in their interpretation of the public message arising from the data.

Lastly, it was speculated that one rich avenue for promoting deeper discussions involves the aspect of nuance that was so aptly captured by the physics student's passage on the competing interests of environmentalists and farmers that was presented previously. One way to highlight the importance of perspective and bias in messaging would be to run the CPP project with half as many numerical modeling projects but the same number of teams. This would mean that two physics students would work with one set of modeling data from which each would write a report. Either by asking the physics students to attempt to push the narrative toward the interests of one of the various stakeholders affected by the study, or by requiring the graphic designers to support opposite perspectives in the infographic messaging, it is expected that this CPP project could become a source of rich and fascinating debate, demonstrating the power of spin, an important lesson in a world constantly inundated with messaging.

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