Designing a Nitrogen Dioxide-Sensing Cubesat to Measure Air Pollution over Cities

(Technical Paper)

Using the Head-Heart-Hands Model to Engage Non-experts in Environmental Awareness

(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction:

Climate change is increasingly prominent in the media and the public eye, and while we understand more about its consequences every day, our ability to pinpoint its sources and reform environmentally harmful practices is years behind where it needs to be (Ebi et al. 2017, p. 2). It is no secret that large cities and population centers produce the vast majority of airborne pollutants; major transportation grids, blocks of manufacturing industries, and population-dense urban centers, as well as the (usually non-renewable) plants that provide power to all of these areas, are critical sources of air pollution within city limits.

However, pollution monitoring equipment can be cumbersome, expensive, and provide limited range or coverage (Atkinson 2017, n.p.), often resulting in a lack of accurate, meaningful air pollution data within a city. Because of this, concerned parties are turning to outer space for effective means of observing, pinpointing, and quantifying this pollution. Satellites have been used for environmental observation for decades (Riccob et al. 2011, p. 664), and the rise of private space industry has resulted in a boom of space technology and a sharp downturn in the price of space missions. One of the most accessible of these innovations has been the Cubesat Standard - a system and measurement standard for building and launching satellites comprised of 10x10x10cm cube units. The cheap and standardized nature of these cubesats make them optimal for small businesses and academic institutions alike.

Climate change has already resulted in a global temperature rise as well as a massive swell in natural disasters resulting in death, displacement, and destruction of property. Over time the severity will only increase. A large part of this global climate disaster is a simple lack of accessible and straightforward information about climate change on the local level; current climate-observation satellites observe regions or even nations, but none focus on individual cities (Myllivirta & Howard 2019, n.p.). Comprehensive climate change reform must begin with providing accurate, easy-to-understand information which is accessible to everyone. For my thesis project, I will work in a Spacecraft Design team to develop a cubesat capable of detecting nitrogen dioxide emissions through spectrography to a resolution of approximately 0.25mi x 0.4mi. Additionally, I will conduct research on the most effective ways to disseminate and communicate air pollution data in a manner that is easily accessible and understandable by the general public.

Technical Topic: Designing a Nitrogen Dioxide-Sensing Cubesat to Measure Air Pollution over Cities

From the very first Sputnik launch, space missions have always been preoccupied with cost-effectiveness. However, during the first age of spaceflight, the prioritization of discovery and scientific innovation over efficiency and price, as well as the domination of spaceflight by national space agencies, pushed successive launches further and further into more scientifically complex - and therefore more expensive - territory (Swartwout 2011, n.p.). As the space race began to decline and in-house missions gave way to contracts with private companies, the shift towards maximizing affordability finally began. The term "smallsat", referring to any satellite, first sprung up in the 1980s, and in 1985, Surrey Space, Ltd. became the first private company focused on designing and retailing smallsat parts (Riccob et al. 2011, p. 665).

In 1999, Professor Bob Twiggs proposed a project to his aerospace engineering class at Stanford: design a small, Sputnik-like satellite mission from the ground up. What started as a straightforward final project turned into a multi-university endeavor, as Twiggs partnered with

Prof. Jordi Puig-Suari of California Polytechnic (Werner 2017, n.p.) to develop the Cubesat Standard, an entire system of smallsat specifications (more specifically, nanosats - satellites less than 5kg in weight). These standards sparked an entirely new approach to unmanned space missions - a unified system of dimensions and modeling based around using cheap, off-the-shelf components to rapidly construct nanosatellites in a matter of months, on budgets hovering right around $100,000 USD. The first cubesat was launched in 2003 and established the "ridesharing" trend of taking up unused payload space on other, larger space missions (Swartwout 2011, n.p.). While cubesats began as a purely academic exercise, the private space industry quickly picked up interest due to their low cost and ease of manufacturing, as well as the standardized size and weight guidelines. In 2011 NASA established its own Cubesat Launch Initiative (CSLI) with the goal of partnering with academic institutions and private companies to provide funding and launch methods for cubesat missions in exchange for data gathered from each mission (Crusan & Galica 2019, p. 55). To date, more than 2000 cubesat missions have been launched, with more than half being private industry missions.

While there are many satellites, both small and large, with earth-pointing systems based on monitoring emissions, all of these are built around monitoring large swaths of the earth at a time (Landsat-9 2019, n.p.). As such, there is not a single satellite currently in orbit with the resolution necessary to detect air pollution - usually measured through nitrogen dioxide levels - to a pinpoint within a city. A satellite that can detect differences in air quality between neighborhoods or even city blocks is critical for understanding the pollution hotspots in and around urban areas. Pictured below is a comparison between the projected worst-case resolution of the cubesat (right) against the current resolution of TEMPO a European Space Agency Climate-Monitoring Satellite (left).

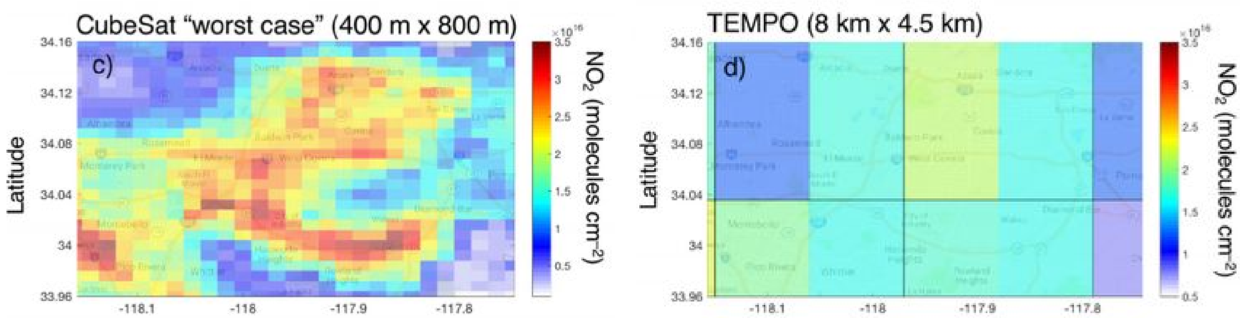

Figure 1: Projected cubesat resolution vs current resolution of TEMPO, a currently deployed ESA satellite
Adapted from the 2018-2019 Spacecraft Design Team, "Mission Proposal"

Monitoring the environmental health of a region or country as a whole is certainly beneficial, but this tactic completely disregards the bottom-up community oriented approach of monitoring pollution sources within a city. Climate change is as critical for individuals and communities as it is for nations, and failing to address this will alienate the groups that stand to gain the most from environmental reform. Additionally, climate change is a ticking clock; in the multi-year time span it takes to propose, design, and launch a traditional large-sat pollution monitoring mission, many more drastic environmental changes may occur.

I will work with Prof. Chris Goyne and his graduate students to continue the design and construction of a cubesat containing an onboard spectrometer, as well as all of the hardware and software needed to process and communicate the spectrographic data back to the UVA ground station. One of the largest challenges will be designing the highly sensitive system of lenses within the spectrograph to fit within the confines of the cubesat, while at the same time ensuring it is sturdy enough to survive launch and deployment. By the end of this school year, we intend to submit a valid critical design ready for subsequent construction and testing.

STS Topic: Using the Head-Heart-Hands Model to Engage Non-experts in Environmental Awareness

While climate change is at the forefront of both political debate and media coverage, it can still be difficult to understand. Scientific reports on the matter can be challenging to find and access, and media coverage tends to focus on the impact through appeal to emotions rather than the underlying causes and implications. As the gap between the educated minority of climate experts and the non-expert general public grows, the search for effective ways of engaging and communicating critical climate information to the public continues. The concept of public engagement in science is not a new one; numerous governments have launched public science engagement initiatives within the last 50 years, to mixed success (van Est 2011, p.641). Initiatives such as the United States' short-lived Office of Technology Assessment and The Netherlands' Broad Societal Discussion around Energy Policy are important steps, but the failures of these initiatives highlight the shortcomings of a top-down approach focused on involving the public without adequately educating them or giving them a reason for engagement.

A more bottom-up, community-oriented approach shows more promise. Studies adapting the head-heart-hands approach have met success using this multidimensional method to encourage community engagement. This approach divides said engagement into three critical parts: Cognitive, increasing the extent to which an individual "engages in constructive thoughts on the topic" (Geiger et al. 2017, p. 223); Affective, building emotional responses and investment in the topic; and Behavioral, establishing agency and participating in actions which address the topic (Geiger et al. 2017, p.224). The head-hands-heart approach not only focuses on educating participants in the science involved, but on building an emotional connection to the subject and encouraging action to be taken. Pictured below is a simple representation of the 3 areas of the head-hands-heart model.

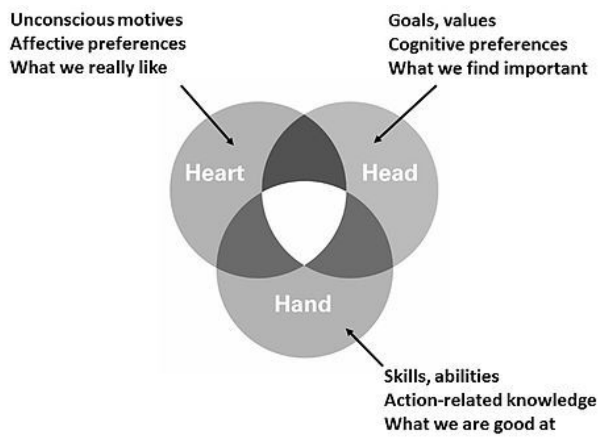

Figure 2: Simple representation of the head-hands-heart model
Adapted from Kehr 2004, n.p.

Citizens, companies, and governments in urban communities have few effective ways of gauging the sources, magnitudes, and effects of air pollution in their cities (Myllyvirta & Howard 2019, n.p.). There must be a means not only to educate citizens in polluted environments on the causes and effects of air pollution, but also to incite action, and develop a reproducible framework of education, leading to emotional investment leading to action to mitigate air pollution. Innovation in community engagement must, naturally, begin at the community level; but this same innovation must be reproducible in various communities across political and geographical regions.

While the negative physical effects of air pollution cannot be understated - particularly a spike in mortality rates and an increase in respiratory defects (Chiusolo et al. 2011, p.1233), the cultural implications of a lack of community engagement are just as dire. In the same way that each component of the head-heart-hands model feeds into the next, a missing stage prevents the next step from being taken. Lack of education leads to a lack of emotional investment in the subject, which leads to an absence of action. Absence of action in a community prevents other communities from noticing and becoming engaged themselves.

I will conduct research into the head-hands-heart model of community engagement to discover an effective means of informally educating citizens on climate change, encouraging emotional investment in the matter, and developing a means for each individual to take action against the negative effects of climate change. The main challenges faced in this research will be finding the most effective methods of teaching non-experts the necessary information, as well as finding a method of emotionally connecting the individual to the issue. By the conclusion of my research I will present a model for implementing the head-hands-heart approach to engaging the community on climate change that can be used regardless of differences between the individual communities.

Conclusion:

By the end of this research I plan on achieving two things: 1) a critical design review for the nitrogen dioxide-sensing cubesat, including the finalized mission objectives, mission architecture, and complete structural and system design; and 2) a deeper understanding of the head-heart-hands approach to community engagement and its applications for educating citizens on climate change, encouraging emotional investment in the environment, and inciting action against the negative effects of climate change. If these two goals are completed successfully, and from their results the cubesat mission and the research on community engagement are appropriately implemented, the data received from the cubesat will pinpoint areas of high pollution around high population cities such as Los Angeles and Shanghai. These areas may include manufacturing districts, high-traffic roads, and high population urban centers.Then, using a teaching model developed from the community engagement research, we will utilize the air pollution data to inform members of the affected communities about the implications of said air pollution, emotionally invest them in mitigating the pollution and its negative effects, and ultimately incite action among community members to combat these negative effects.

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