Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 00 (2015) 000–000

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

Exploring local micro-climates with an open-source mesh of sensor motes

Kenneth Y T Lim[a]*, Collin Chan[b], Richard Lee

[a]*National Institute of Education, 1 Nanyang Walk, Singapore 637616*
[b]*Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798*

Abstract

This paper describes an on-going effort in a school in Singapore to leverage a networked mesh of open-source environmental sensors to help teachers surface students' evolving intuitions and conceptions about their local microclimate through a STEM-based curriculum. Data polled from the sensors is represented visually in an immersive environment which is a facsimilie of the school campus. Students' intuitions about geography and other disciplinary domains are – by definition – tacit, yet they are critical in shaping understanding of broader disciplinary concepts. Through surfacing such intuitions in ways which are authentic to the students, the former become boundary objects which can subsequently be dialogued about with peers and teachers.

Keywords: Open-source; Raspberry Pi; Arduino; Mote; Environmental science; Immersive environment; Data literacy; Geographical intuition; Micro-climate

1. Introduction

Designing curriculum around Science, Technology, Engineering and Mathematics (STEM) is often predicated upon finding tasks which are meaningful and authentic to students. In June 2013, Singapore experienced transboundary air pollution so severe that the Pollutant Standards Index (PSI) of air quality reached the maximal

* Corresponding author. Tel.: +65-96266808; fax: +65-65151992.
E-mail address: kenneth.lim@nie.edu.sg

level on the scale - termed as ‘hazardous’ - regularly. Although such transboundary air pollution arising from slash-and-burn agricultural practices in neighbouring Indonesia has been a well-documented phenomenon in the region since the 1990s, the levels of air pollution experienced in Singapore during June 2013 were unprecedented.

Many Singaporeans felt aggrieved that their country and lifestyles should be adversely impacted by the socio-cultural practices of a neighbour across the straits. The Not In My Backyard (NIMBY) argument, with its corollaric fable of the Tragedy of the Commons [1], describes the dangers inherent in externalising the natural environment as an economic resource with a minimal cost. Given this latter framing, it is perhaps not too surprising that Singaporeans - shielded by geography as they have been from a great diversity of natural hazard and calamity that otherwise affects all its neighbours (namely, typhoons, tsunamis, earthquakes and volcanoes) - should be up in arms when they perceived that ‘their’ air was being polluted through no apparent fault of their own.

The relatively multi-disciplinary nature of Environmental Science (together with its Values orientation) makes it an ideal candidate for STEM-based curriculum design. Traditionally, however, data presented to students is often abstract, decontextualized, and presented in forms which presume relatively high numeracy and graphicacy among students. Thus, for example, during the National Weather Study Project 2007-9, participating schools were given a set of weather instruments, with a view to ‘crowd-sourcing’ weather data for Singapore. The resulting datasets were too coarse to be meaningful to students; for example, from the point-of-view of a student in one part of the island-nation, it would not have been very meaningful or authentic to know that it was raining somewhere else the preceding day.

Especially because conventional weather data is complicated by the microclimate of the built environment, especially of urban heat island effects, conventional methods may not be particularly suited to the very dense urban geography of Singapore. As students typically have no access to a mesh of data points, and means to observe concomitant weather phenomena, the cause-and-effect reasoning is usually abstract and far removed from the experience of the daily lives. With their own sensor mesh and a means to visualise the data, we believe students will be better able to ‘talk’ through these data to surface their intuitions, confront them, and develop means to move from nascent forms to more expert forms of knowledge.

Given this context, we are interested in investigating how children in Singapore perceive and understand the factors affecting, and systemic relationships between, their local environments. Specifically, an exploratory study is being conducted in collaboration with a school which has been established with the mandate to approach STEM education with at-risk students in novel and authentic ways.

Through the use of a network of low cost, open-source, unobtrusive environmental sensors placed throughout the school campus, teachers in the school are designing curriculum involving geography and science which would permit and encourage the interrogation of real-world micro-climatic data from within an environment already familiar to the students, so that their intuitions about local environmental factors and systemic relationships - which would otherwise have remained tacit - might be surfaced and dialogued upon in collaboration with their peers and teachers.

2. Review of literature

Context matters in geography, both in terms of physical geography and in terms of human geography. Thus, the fields of grey – for example, climatology and pollution – betwixt these two major domains might have much to help us articulate the nature of geographical intuition, rather than just being “an inconvenient truth” [2]. Geography is – after all – primarily about the relationship between humans and the environments in which they inhabit.

This latter notion of habitation is important because it comes with the concomitant concept of the lived experience – which is very much bound in socio-cultural context (among other parameters).

In fact, formal descriptions of how man thinks about the local environment are not new. Perhaps the most influential thinker on this issue has been the geographer Yi-Fu Tuan. Writing in 1976, Tuan described the concept of topophilia, as the study of how the land influences the way one thinks, particularly through the affective bond between people and place [3].

One of the most critical aspects of topophilia is Tuan's use of different (spatially defined) lenses through which the dialectical relationship between affect and land might be interrogated. Thus, for example, Tuan considered the city, the suburb, the countryside, and wilderness areas as all imparting distinct affordances to the mediation of topophilia.

With a doff of the hat to Vygotsky [4], it is also worth considering the extent to which the preceding place-based nouns – city, suburb, countryside, wilderness – are bound deeply in culture and mediated through language. This point is not trivial, and is perhaps best illustrated in the inexact degree of congruence in meaning among the English 'country', the French '*pays'*, the German '*Land'*, and the Latin '*pagus'*.

Indeed, Kong [5, 6] has argued that children and adolescents in highly-urbanised Singapore view nature as something which is orderly and well-maintained. She continues that this rather limited perception arises from the fact that nature is "a 'waste of time'. All the teenage members of the school group acknowledged that nature was not very much a part of their consciousness. When bored and thinking about places to visit and what things to do, the tendency was not to think of activities associated with nature. When thoughts about the natural world did surface in their minds, it was often in the context of school work, for example, their geography lessons, during which nature was more about conceptual issues and scientific processes than everday environments of potential fun and enjoyment" (Kong, 1999:3).

The phrase 'a waste of time' as remarked upon by Kong is interesting, not least because time – or more specifically, one's sense of the passage thereof – is noted by Tuan [7] as shaping topophilia, at both the scale of the individual as well as that of the community. That nature might be considered 'a waste of time' by children and adolescents in Singapore suggests that there are indeed few opportunities – either engineered by others, or by they themselves – for the development of geographical intuition.

Kong's observations are therefore important because it is our considered position that such "everyday environments of potential fun and enjoyment" constitute the substrate upon intuitions about geography – intuitions about the nature of the man-land relationship – are formed and developed. Such intuitions, in turn, shape geographical ways of knowing, and are thus critical to informing how novice geographers (such as students in school) approach and understand the world.

We advance the thesis that – at least with respect to the relationship between humans and the natural environment, and the way this relationship is approached in the formal curriculum – alignment between the assessment of children, and their day-to-day lived experience is critical to developing enduring understanding beyond rudimentary textbook recitation. We suggest that an overlooked element of this alignment has been the role that intuitions about geography play in shaping such understanding, and how these intuitions can sometimes be very powerful in lensing understanding either accurately or inaccurately. The challenge – from the point of view of curriculum designers (who are, by definition, disciplinary experts) – is in reminding ourselves of just how subliminal some of these day-to-day lived experiences might be.

3. Intervention design

Together with teachers in the school, we designed an exploratory study in which environmental datasets reporting from within the school and generated in real-time by a networked mesh of open-source sensors are used as boundary objects around which students and their teachers will be able to engage in interrogative dialogue with each other.

The sensor mesh at the school campus consists of environmental sensor nodes communicating with a few hub devices (which collect sensor data and transmit it to a central server). Each sensor node is made up of the following components: a) environmental sensor, and b) Arduino Leonardo micro-controller with wireless module (for transmitting sensor data). The hub device consists of a Raspberry Pi computer board with wireless modules (for collecting and transmitting sensor data).

Typically, an intervention would begin with an introduction to the environmental sensors and the various environmental variables that might be measured. During this initial workshop, students would have access to the open-source hardware (either individually, or in small groups) and would be given at least an hour to go through an orientation activity. They would also have the benefit of having mentor-figures (teachers, or members of the research team) on hand. After this initial workshop, most of the lessons are held during curriculum time in regular classrooms. These would comprise the lesson activities in subjects such as General Science.

A possible scenario of how such a lesson might unfold over time might be: a teacher might ask the class, "it's been pretty hazy these few days. Which part of the school do you think has the worst quality of air?" "What about the most humid part of school?" "What about the shadiest?" "When?" "Why?"

By responding to these (and similar) questions, the students would surface their intuitions (valid and / or invalid) about factors influencing their local microclimate. It is important to note that the responses from the students would be distinct from either prior knowledge or preconceptions. This is because the line of questions addresses the lived experience of the students, and not their decontextualised preconceptual ideas of a topic in abstraction. This latter point illustrates how disciplinary intuitions should not be confounded with existing literature on misconceptions nor on prior knowledge, in terms of curriculum design.

The problem that this study attempts to address is that not every school would have a functional weather station within its premises, and for those which do not, the line of inquiry might well end with the students responding to the teacher's first round of questions. For schools with a functional weather station or a set of portable weather instruments, the inquiry could potentially continue with the teacher saying, "now that we have got your responses, let's see what we can do to verify your hypotheses".

However, even then, the result would be a pointilistic description of data from the weather instruments, which would be limited in both temporal as well as spatial coverage (this is because weather instruments are expensive, schools have limited sets, and teachers do not have the luxury of time to get the students to take readings over an extended period of time, because of the opportunity costs).

Pollutant Concentrations

Readings on 23 Jun 2013

View reading for: 7PM

Region	24-h Sulphur dioxide (µg/m^3)	24-h PM10 (µg/m^3)	1-h Nitrogen dioxide (µg/m^3)[a]	8-h Ozone (µg/m^3)	8-h Carbon monoxide (mg/m^3)	24-h PM2.5 (µg/m^3)[b]
North	24(15)	127(88)	44(-)	100(42)	2.3(23)	77
South	25(15)	134(92)	73(-)	34(14)	1.5(15)	92
East	19(12)	111(81)	73(-)	45(19)	0.8(8)	85
West	28(17)	149(99)	49(-)	105(45)	1.4(14)	97
Central	15(9)	111(81)	22(-)	70(29)	0.9(9)	71

Note:
Figures in bracket are the PSI sub-indices
[a] Sub-index for nitrogen dioxide is reported only when the 1-hour concentration exceeds 1130 µg/m3
[b] There is no sub-index for PM2.5

3-hr PSI Readings from 12AM to 11.59PM on 23 Jun 2013

Time	12AM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM
3-hr PSI	91	90	88	89	93	99	104	106	105	101	96	90
Time	**12PM**	**1PM**	**2PM**	**3PM**	**4PM**	**5PM**	**6PM**	**7PM**	**8PM**	**9PM**	**10PM**	**11PM**
3-hr PSI	83	80	78	78	77	77	76	**75**	-	-	-	-

Hourly updates of 3-hr PSI readings are provided from 12am to 11:59pm. The 3hr PSI readings are calculated based on PM10 concentrations only.

Fig. 1. Example of pointilistic representation of environmental data.

Because of the preceding constraints, the data would not approach anything rich enough to be plotted meaningfully as time-series on Cartesian graphs. It should also be evident that even if sufficient data were somehow to be generated, they would still not address a further problem associated with the representation of such datasets, namely that the graphs and charts would be difficult to meaningfully interpret because they would have been decontextualised into only two dimensions (ie, the microclimatic variable over time); the role of space as a context underpinning the variable would have been stripped out.

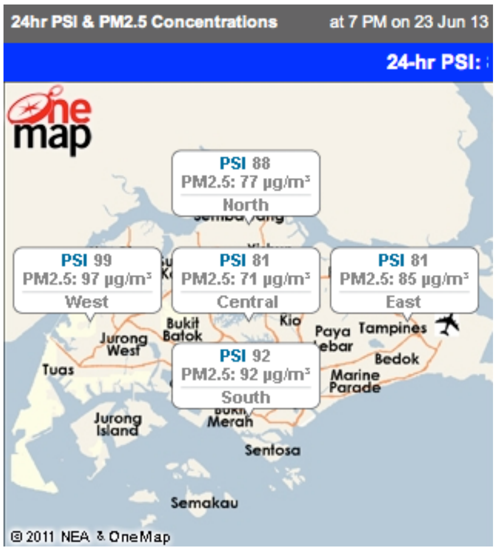

Fig. 2. Example of environmental data with limited spatial context.

The study addresses these limitations through the combination of open-source sensors measuring various aspects of environmental quality with a scale-rendition of the school compound in an open-source immersive digital environment (OpenSim). Because of the relatively low-cost of the sensors, we will eventually be able to cover the school compound with a much finer mesh - over both space and time - of data-loggers than the pointilistic and opportunistic method of having students take readings only during a limited duration of (say) their Science lesson.

Just as significantly, we are able to put the context back into learning [8] by retaining the spatiality of the datasets (as opposed to reductively purposing them as two-dimensional Cartesian representations of time-series) by plotting the datasets in their actual positions using the immersive model of the school's campus - this will thus allow the students to interrogate the data with respect to topography, intervisibility, time of day, solar incidence, etc (all being factors which would not otherwise be able to be represented using traditional Cartesian graphs). Further, we are able to leverage the virtuality of this three-dimensional model by manipulating the representation of the passage of time within the immersive environment, thus (for example) allowing the students to study how the variables behave over time and space - over the course of a week - all potentially within a standard 35-minute lesson.

Gee [9], has written about the role of what he has termed Projective Identity in game-based learning. Briefly, Gee describes how – in well-designed learning environments – a learner might potentially develop a Projective Identity as an amalgam which complements both his or her atomic (human) identity and the virtual (avatar) identity, and how such Projective Identities might persist beyond the instantiations of the game and / or the immersive environment to influence values and behaviours in other (non-game) contexts. Gee's thesis thus speaks directly towards the present framing of intuitions as developed through the lived experience, which can therefore include embodied experience in both human- and avatar-based settings.

For example, the diagram below illustrates how variables might be represented within an immersive environment, in terms of colour, shape, diameter of base, height, and translucency. In turn, these multiple dimensions are contextualized according to the environment's topography, taking into account other influencing variables such as the time of day and solar incidence (note the shadow in the foreground).

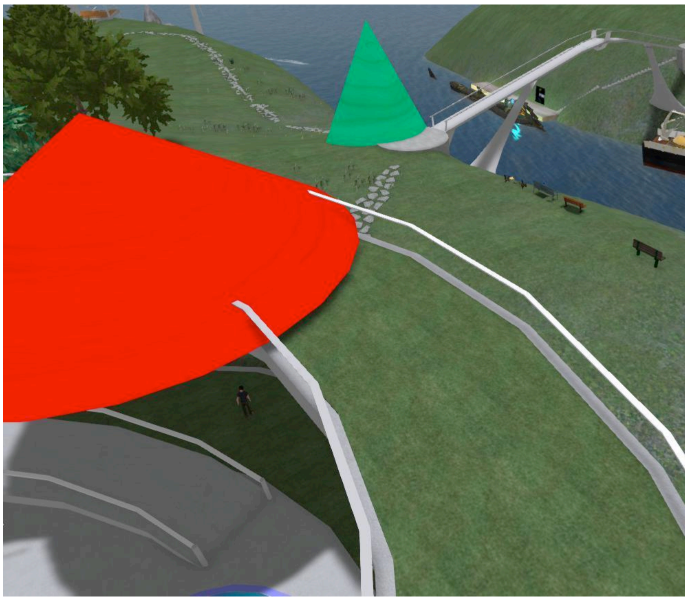

Fig. 3. Example of how the proposed intervention lends rich spatial context to environmental data.

Through the study, we are therefore able to design learning environments which provide students and teachers with boundary objects (in the form of time-series data represented over a three-dimensional space and over time) which could subsequently be dialogued about as students seek to verify their intuitions against empirical data generated by a fine mesh of open-source sensors monitoring the school's local environmental quality.

Finally, the datasets might also be used in a proactive manner by staff and students to conceptualise and design measures to improve the quality of the school environment, such as in terms of noise, shade, and air quality.

4. Concluding remarks

There are several advantages to this approach over any other potentially competitive design at similar levels of cost.

First, the approach builds data literacy and graphicacy among the learners, as they seek to analyse, interpret, and re-present the datasets to support their inferential activities (the 'M' (Mathematics) in STEM).

Second, the approach is timely because initial enactments are being carried out while learners' memories of the haze from 2013 are still relatively fresh - they would be better able to appreciate the purpose of their field-based inquiry.

Third, the approach is only recently technologically feasible, in that it leverages not only open-source software, but the open-source hardware movement. It is only because of the widespread availability of open-source hardware such as Raspberry Pi and Arduino that devices can be custom-built to suit very particular learning needs at affordable costs, and - very often - by the learners themselves (the 'E' (Engineering) in STEM).

Fourth, the approach provides an objective source of data against which teachers and students might compare their own subjective interpretations of local environmental variables within the micro-climate of the school campus. This would potentially lead to learners being more effective in self-monitoring and questioning their own assumptions.

Fifth, the approach is authentic to the learner because it involves the interrogation of datasets generated from within a campus which they are already familiar with, as opposed to any similar efforts in the past in which the data would have been obtained from neighbourhoods unfamiliar to the learners. Because of this local-ness, learners will be able to frame their analysis, interpretation, and re-presentation of the data in terms of shared understandings and discourse-structures (eg "data from sensor A shows that it's consistently more humid than that from sensor B; we understand why, since sensor A is positioned closer to the cooker hood in the canteen than sensor B (which is nearer the staff seating area in the canteen”).

Finally, because the devices are affordable and easy to customise (open-source hardware), they can be placed in a much finer mesh around a limited space than was formerly possible - the datasets will therefore be potentially much less granular (both in terms of time and space) than before, allowing for increased opportunities for learners to practice their deductive and inferential skills (please refer to the preceding paragraph for an example). These fifth and sixth advantages address the ‘S’ (Science) in STEM.

Acknowledgements

The authors would like to acknowledge that funding for the work described is drawn from SUG 9/13 LYT granted by the National Institute of Education, Singapore.

References

[1] Hardin, G. 1968. The Tragedy of the Commons. Science 162: 1243-1248.
[2] Gore, A. 2006. An inconvenient truth. Paramount Classics.
[3] Tuan, Y.-F. 1976. Topophilia: a study of environmental perception, attitudes, and values. Prentice-Hall, Englewood Cliffs, NJ.
[4] Vygotsky, L. S. 1978. Mind in Society. Cambridge, MA: Harvard University Press.
[5] Kong, L., Yuen, B., Sodhi, N. & Briffett, C. 1999. The construction and experience of nature: Perspectives of urban youths. Tijdschrift voor Economische en Sociale Geografie. 90(1) 3-16.
[6] Kong, L. 2000. Nature's dangers, nature's pleasures: Urban children and the natural world. In S. Holloway & G. Valentine (Eds.) Children's geographies: Living, playing, learning (pp 257-71). London: Routledge.
[7] Tuan, Y.-F. 1977. Space and Place: The Perspective of Experience. University of Minnesota Press, Minneapolis, MN.
[8] Hung, D., S.-S. Lee and K. Y. T. Lim. 2012. Authenticity in learning for the 21st century: Bridging the formal and the informal. Educational Technology Research & Development, 60(6) pp, 1071-1091.
[9] Gee, J. 2003. What video games have to teach us about learning and literacy. New York, NY: Palgrave.