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Research Article

An Evaluation of Best Practices in an Air Quality Student Science Project in Ethiopia

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ABSTRACT

A science project as part of a student's curriculum, which we call student science, might be the answer to two problems for a low-income country like Ethiopia: conventional science can be expensive and many students lack training in practical skills. Earlier studies have been conducted with respect to lay people (citizens or students) conducting (parts of) research (e.g. citizen science), but rarely in the context of a public university in a low-income country. A student science project at Arba Minch University (Ethiopia) has been evaluated in three steps. Firstly, best practices for student science projects are derived from the literature. Secondly, it is evaluated to what extent these best practices were executed in an air quality student science project executed by 33 groups of undergraduate students at Arba Minch University. Thirdly, the scientific contribution of the project is evaluated by assessing the quality of the data in comparison to studies in similar scenarios, as well as its relation to a knowledge gap and a problem for the community. We find that the best practices from earlier studies are feasible in the study context. Furthermore, we find a scientific contribution, as most of the students' work resulted in quality data that relates to knowledge gaps which are a problem for the Arba Minch community. Student science at a public university in a low-income country is feasible and can, as such, serve both scientific and educational needs. It is recommended that public universities in low-income contexts implement part of their curriculum goals in such projects.

Keywords: air quality, campus exposure, public university, Ethiopia, student measurements, practical university education, citizen science, student-teacher-scientist partnerships

INTRODUCTION

Scientific Developments

Within a low-income country such as Ethiopia, there is a paradox between a relatively heavy burden of disease due to air pollution (World Health Organization, 2018), and limited conventional (expensive) air quality monitoring equipment and research (Abraham & Li, 2014; Rebeiro-Hargrave et al., 2020; Roychowdhury et al., 2016). Finding cheaper ways to research air quality can resolve this paradox. A means to this end is citizen science, i.e. the practice of science by people who are not affiliated with credentialed academic or research institutions (Kimura & Kinchy, 2016), or science by lay people. Cheaper self-made instruments are being used (for example in Bulot et al., 2020; Jiang et al., 2016), and the data collectors might do the work voluntarily. In this way, for the same order of magnitude of data collection, less money is needed. Similarly, scientists involve students in science projects, as part of the students' curriculum (Evans et al., 2001; Houseal et al., 2014; Lawless & Rock, 1998; McLaughlin et al., 2016; Peker & Dolan, 2012; Wormstead et al., 2002).

Educational Developments

Involving students in science as part of their curriculum suits well to the recent educational paradigm which started in the 1980s by the USA National Committee on Excellence in Education (1983). The underlying belief was that the 'new workforce reality (...) demands (...) independent thinkers, problem solvers and decision makers' (Silva, 2009, p. 630), education must not just teach the basics and focus on knowledge accumulation, but education must make students gain thinking, working and reasoning skills (Silva, 2009). We encounter this idea also in Ethiopia's scientific community. At Ethiopia's second science congress, titled 'Re-envisioning Higher Education and Research in Ethiopia', Bililign (2015) argued that education should focus on core skills such as critical thinking, collaborative working, effective communication across disciplines and cultures, and learning how to (want to) learn. A format of such education is project-based learning, in which 'students drive their own learning through inquiry, as well as work collaboratively to research and create projects that reflect their knowledge' (Bell, 2010, p. 39). In Ethiopia, a shift from theoretical-based education to practical and inquiry-based education is much needed. The current, often theoretical-based, education results in a gap between graduates' skills and employers' demands and may contribute to youth unemployment (Reda & Gebre-Eyesus, 2018; Yibeltal Yizengaw, 2018).

Student Science Combines Scientific & Educational Goals

When combining the above-described developments in science and education, one could argue that cooperation between scientists and students may result in a win-win situation. The scientist gets research assistants and measurement results and may be inspired by the creative input of her/his students. The students get a real-life problem-solving situation which will encourage inquiry-based learning, preparing them for being useful employees. This phenomenon, scientists and students working together to reach scientific and educational goals, is not new. The literature uses different terms: student scientist partnerships (SSPs) or student teacher scientist partnerships (STSPs) (Evans et al., 2001; Houseal et al., 2014; Lawless & Rock, 1998; McLaughlin et al., 2016; Peker & Dolan, 2012; Wormstead et al., 2002), Research apprenticeships (Sadler et al., 2009), and citizen science by students (Mitchell et al., 2017; Zoellick et al., 2012). Bililign (2015, p. 144) suggests the term *research-based teaching* for the Ethiopian context: 'In this approach courses are designed largely around inquiry-based activities, rather than on the acquisition of subject content'. To recognize that each of the different terms and related studies hold relevant aspects, not one of them is selected, but instead the term 'student science' (SS) is used. This term is chosen in line with the term citizen science, stressing the value of both scientific and educational goals, and with the knowledge that practical skills are reached when students are not only *in partnerships with*, but really *are* the scientists.

Research Gap and Problem Statement

Different SS projects have been subject to research. However, we could not find a published academic source evaluating such projects on public universities in low-income countries, even though the need for affordable data collection and practical education in low-income countries like Ethiopia is notable (Reda & Gebre-Eyesus, 2018; Yibeltal Yizengaw, 2018). There is a gap in literature on the evaluation of SS projects in the context where budget for science is low and students are hardly practically trained. It is unknown whether this academic context impedes an SS project, or if an SS project is feasible and able to facilitate affordable data collection and practical training. Also, the scientific contribution of an SS project on a public university in a low-income country has not yet been evaluated in the literature. This leads to the following problem statement: there is a lack of insight in the feasibility and scientific contribution of involving students in research as part of their education on a public university in a low-income country. Therefore, this study wishes to evaluate the feasibly of an SS project, and its scientific contribution, in the context of a public university in a low-income country.

Outline of the Study

To determine the feasibility of an SS project, an 'ideal' SS project is defined, based on scientific and educational best practices in the literature. Next, a case study is conducted on an air quality SS project that took place at Arba Minch University, Ethiopia. This air quality SS project is evaluated on scientific and educational best practices, to investigate the feasibility of an SS project in a low-income country. Lastly, scientific contribution of the air quality SS project is evaluated.

LITERATURE REVIEW

Literature concerning science by lay people (citizens or students), with or without cooperation with scientists, is reviewed. Based on this literature, best practices for successful SS projects are described. We first address the scientific best practices, and next the educational best practices.

Best Practices in Reaching Scientific Goals with SS

Scientific goals of an SS project are that the students (i) obtain quality data and (ii) generate scientific knowledge (Lawless & Rock, 1998). From the literature best practices to reach these scientific goals in an SS project are separated over five categories:

1. It is important to offer training to the students (Aceves-Bueno et al., 2015). There should be a standardized set of training sessions (Evans et al., 2001; Freitag & Pfeffer, 2013). Part of this training should focus on the required precision and accuracy, as this will enhance data quality (Parrish et al., 2018).
2. Quality can be further assured when a plan of measurements is made before the start of data collection. This plan establishes what will be done, and how it will be done. For general tasks standardized research protocols and methodologies can be used (Aceves-Bueno et al., 2015; Evans et al., 2001; Freitag & Pfeffer, 2013; Lawless & Rock, 1998). A design specific to a certain topic is important to ensure the quality of tasks that cannot be generalized (Parrish et al., 2018).
3. Students should be supplied with adequate equipment: equipment that is relevant to the topic, and that is of adequate quality (Aceves-Bueno et al., 2015; Lawless & Rock, 1998).
4. After data collection, data quality can be enhanced by validation of data (Parrish et al., 2018). Identification of potential sources of error will help in general (Lawless & Rock, 1998). As for the data itself, questionable identifications can be checked by experts (Aceves-Bueno et al., 2015), or validated by multiple measurements (Lawless & Rock, 1998). Student's self-awareness of data reliability is enhanced if students conduct peer reviews (Mitchell et al., 2017).
5. Throughout the whole process, data quality is enhanced if students have access to experts, through regular contact (Boersma & Vroom, 2006; Evans et al., 2001; Lawless & Rock, 1998) or collaboration (Freitag & Pfeffer, 2013).

Best Practices in Reaching Educational Goals with SS

To be an SS project, also *educational goals* need to be sought. These vary, and are related to the curriculum and to different skills to be trained. The best practices to reach educational goals with SS can be grouped into four main categories:

1. Curriculum's knowledge goals can be reached with SS, if the science project is in line with learning requirements (the student's curriculum) (Zoellick et al., 2012). Observing and empirically verifying knowledge claims of curricula, inquiry-based learning (Tafoya et al., 1980) will 'support (...) the integration of practices and concepts' (Houseal et al., 2014). Not only will this help to understand the concepts, but it might also alter the student's perception of the curriculum's topics. Ortiz (2018) has shown that students' perception on nature changed positively after joining a biology data collection project.
2. Inquiry-based learning can be an educational goal in itself. This means that students are trained in a scientific way of thinking and working. While traditionally the science curriculum included 'what one needs *to know* to do science', the newer perspective focuses on 'what students need *to do* to learn science' (Duschl, 2008, p. 269). When scientific practices are introduced earlier and more often in the curriculum, by letting students *do* authentic science, students will get an improved understanding of core science contents and have deeper engagement with science (Zoellick et al., 2012). Related to inquiry-based learning, the following best practices can be distinguished:
   a. Realistic cases (real data and real scientific problems) rather than simplified and abstract cases should be used (Zoellick et al., 2012).
   b. Teachers should not provide authoritarian answers. Students must learn that truth is based on observable science, rather than what the teacher says (Tafoya et al., 1980).
   c. Expose the students to different instructional settings, and to a variety of materials and methods (Tafoya et al., 1980).
   d. Involve the students not only in data acquisition, but also in the other aspects of scientific methods and research (Lawless & Rock, 1998), such as the development of their own research question (RQ) (Evans et al., 2001).
3. It can be an educational goal to enhance students' motivation for conducting science. Literature suggests the following good practices to make students motivated to participate in the science project:
   a. Give students access to experts. Evans et al. (2001) showed that students value access to experts. Working with an expert offers a unique opportunity for personal development (Freitag & Pfeffer, 2013). Ozturk (2015) states that optimal communication with the scientist leads to a change in students' perception on science.
   b. Give feedback to the students. He et al. (2014) found that only giving positive feedback, and feedback with corrective guidance, encourages students to collect more data.
   c. Show the outcome of the students' work in a larger context. This way they are able to see how their work contributed to the bigger picture (Parrish et al., 2018).
   d. Make students owner of their work. Let them select and answer an RQ, which is driven by their curiosity rather than by 'what the teacher says' (Evans et al., 2001; Houseal et al., 2014).
4. A variety of educational goals can be related to the development of different practical skills.

The following practical skills are associated with SS projects:

1. Learning how to develop an RQ makes students think critically about research gaps (Evans et al., 2001).
2. Student peer reviews will make students collaborate and critically evaluate each other's and, in the end, their own work (Zoellick et al., 2012).
3. Presentation of the research trains communication and media literacy skills (Zoellick et al., 2012).

MATERIALS AND METHODS

Introduction of the Case

Student science project set-up

This study evaluated an air quality SS project for students of Water Supply and Environmental Engineering (WSEE; 139 students, year 4) and Meteorology and Hydrology (MHD; 26 students, year 2) at Arba Minch University (AMU), one of the public universities of Ethiopia. The course took one semester (October 2019-January 2020) and was offered by the first author of this article. He had a double role: lecturer and scientist/expert. We will consistently refer to him by using the term *instructor*.

In the SS project, students worked in groups of 4-6 (total 33 groups) on the full research cycle, investigating a self-selected scenario in which they noticed air pollution. The students could pick scenarios related to either carbon monoxide (CO; increased concentrations due to incomplete combustion), particulate matter with an aerodynamic diameter smaller than 2.5 (PM2.5; increased concentrations due to incomplete combustion) and/or carbon dioxide (CO_2; increased concentrations within rooms with people, i.e. ventilation parameter). They produced a measurement plan, collected and analyzed the data, wrote a measurement report and presented their work. The planning of the course is displayed in **Table 1**. The project part of the course consisted of approximately 8 hours of introduction/explanation of all different parts, and 35 hours of working on those parts. The instructor was available for consultancy during 15 of these 35 hours.

Table 1. General course outline of the case study

Week	Activity
1-4	Lectures, scenario selection, and draft measurement plan
5	Feedback and finalize measurement plans
6-8	Lectures and measurements
9-11	Lectures and draft report
12	Feedback draft report, finalize report, and presentations

External validity of the case

We assume this case represents public university settings in low-income countries for the following reasons. Firstly, AMU is a public university, working with limited budget and implementing harmonized guidelines from the Ministry of Science and Higher Education. The SS project fits the regular curriculum schedule and semester planning, and, except for measurement instruments[1], all resources used were available inside the university. Secondly, the project did not select only brilliant or only poor students, because freshmen students are admitted to the program based on moderate entry test scores and all students of the sections participated. Thirdly, the students live in a typical campus setting, with dormitories, small restaurants, classrooms, and other study places, so it is reasonable to assume that students in other low-income public universities have similar access to measurement locations.

Data collection methods

The instruments available were the Lascar EL-USB-CO datalogger (for CO; from hereon: ELCO), the UCB-PATS+ (for PM2.5; from hereon: PATS) and the IQAir Airvisual Pro (for PM2.5 and/or CO_2; from hereon: IQAV). All instruments were prepared by the instructor; students took the instruments while they were working, and only needed to use them at their chosen location. Tasks afterwards (such as data retrieval, zero calibrations, etcetera) were conducted by the instructor.

33 groups conducted a total of 65 measurements, as some of the groups collected multiple data files (for example, inside and outside a restaurant kitchen). The length of measurements ranged from 5 minutes to 5.75 hours (average and median: 1.7 hours), with measurement frequencies ranging from 10 seconds to 5 minutes. For this study, the 65 individual measurements have been ordered into groups that are in a similar situation: restaurants, households, waste burning, ambient environment, and ventilation. **Table 2** shows a summary of the student measurements. Measurements in restaurants were held at different campus cafeterias, and one restaurant in Arba Minch town. Measurements at households were held at different households in Arba Minch. Measurements at waste burning sites were held close (CO 1-40 meter, PM2.5 1-20 meter) to burning of domestic or agricultural waste at the campus. Ambient measurements were conducted in Arba Minch bus station, outside the bus station, at the roadside close to campus, at a smoking area in campus an at the soccer field in campus. CO_2 ventilation measurements were taken in different libraries in campus, some student dormitories, classrooms, and campus cafeterias.

Table 2. Summary of measurement characteristics with number of datafiles (NF), number of data points within these data files (ND), & total measurement time in hours (NH)

ID	Scenario	P	I	N_F	N_D	N_H
	Restaurants					
1A	Visitor area	CO	ELCO	5	1,139	9.3
1B	Kitchen area	CO	ELCO	15	4,584	24
1C	Outside kitchen[a]	CO	ELCO	5	504	8.3
	Households					
2A	Kitchen, wood fuel	CO	ELCO	5	415	6.8
2B	Kitchen, electrified	CO	ELCO	4	245	4.0
2C	Coffee ceremony[b] inside	PM2.5	IQAV	1	360	1.0
2D	Coffee ceremony outside	PM2.5	IQAV	1	360	1.0
2E	Charcoal cooking outside	CO	ELCO	1	60	1.0
	Waste burning					
3A	CO	CO	ELCO	4	1,020	6.9
3B	PM2.5	PM2.5	PATS	1	121	2.0
	Ambient					
4A	Busstation CO	CO	ELCO	1	360	1.0
4B	Busstation PM2.5	PM2.5	IQAV	1	243	2.0
4C	Outside busstation/roadside	PM2.5	PATS (2), IQAV (1)	3	1,931	5.9
4D	Generator[c]	PM2.5	PATS	2	698	1.9
4E	Smoking area	PM2.5	PATS	1	1,099	3.0
4F	Soccer field	PM2.5	PATS	2	130	2.1
	Ventilation					
5A	Library	CO_2	IQAV	3	1,027	9.0
5B	Dormitory	CO_2	IQAV	3	547	7.8
5C	Outside dormitory[a]	CO_2	IQAV	1	96	1.9
5D	Classroom	CO_2	IQAV	2	269	3.6
5E	Restaurant	CO_2	IQAV	4	2,223	9.0
	All			**65**	17,431	112

Note. P: Pollutant; I: Instrument; [a]Some groups conducted simultaneous measurements inside and outside for comparison; [b]The Ethiopian coffee ceremony is the full process of roasting beans up to preparing and serving coffee, usually on a charcoal fire and often together with burning incense; [c]One <25 kVA gasoline generator and one 42 kVA diesel generator

Evaluation of Best Practices for Reaching Scientific and Educational Goals

First, the SS air quality project was compared to best practices as retrieved from the literature in the section literature review. For a full overview of the checklist, please consult **Table 3** and **Table 4**. The checklist was filled based on information from the instructor and course documents. Each determinant received a qualitative score: –(absent); +(partially present); or ++(fully present).

Evaluation of the Scientific Contribution

Operationalization of scientific contribution

A successful contribution to science can be described as obtaining quality data with which scientific knowledge is generated (Lawless & Rock, 1998). Generating scientific knowledge can be further operationalized as filling a *knowledge gap* in relation to a *problem for the community* (Arkato et al., 2018).

[1] The instruments were part of a donation by Buro Blauw, an air quality consultancy company from the Netherlands. The combined costs of the instruments used in the project is approximately $4,200 or ETB 220,000 (per February 2022), which is not beyond the research budget of a public university in Ethiopia. Hence, this donation does not rule out the possibility for other public universities to conduct a similar project.

Table 3. Evaluation of the project versus best practices for reaching scientific goals with a qualitative score (S)

	Best practices	S	Score explanation
Training	1. The training covers all parts of the research cycle	++	Students got the following instruction materials: (1) measurement plan & report instructions; (2) measurement plan & report example; (3) instrument instructions; (4) data analysis instructions and practice in Microsoft Excel, and (5) feedback on measurement plan & measurement report. Formally, all elements of the research cycle were requested in the measurement plan (proposal phase) and the report (analysis, conclusion & recommendations). -Within the measurement plan, the following steps of the research cycle were specifically requested: background as reason to do research, RQ, & methodology (consisting of data collection & analysis). -Within the report, the following steps of the research cycle were specifically requested: background+RQ, methodology, results & analysis, conclusions, & recommendations.
	2. Required precision and accuracy	+	Students were informally encouraged to critically evaluate the quality of the data they collected during the lectures and the consultancy hours. No explicit instruction on precision and accuracy was given.
Plan	3. Standardized research protocols and methodologies	++	Next to the training materials described above, there was a text document with guidelines, framed as 'advice', for the data collection (data collection protocol). The content of this protocol was discussed during the lectures and the students got a hardcopy of this document when picking up the measurement instrument.
	4. Each group makes a measurement plan	++	It was mandatory to write a measurement plan. After one feedback & improvement round, all, except one, measurement plans were deemed sufficient to continue the project by executing the measurements. The group with the insufficient measurement plan was forced by the instructor to use a more adequate measurement instrument.
Adequate equipment	5. Relevance of instruments	+	Before approving the measurement plan, the instructor checked if the right instrument was chosen for the right research scenario. There were two cases in which the relevance of the instrument was doubtful: -Within measurements of scenarios 3C&3D, the maximum range of the IQ air was reached. Hence, it is known that the concentration is high, but the precise concentration is unknown. -For scenario 5C, one dataset of the PATS came back with continuously the lowest reported value. Hence, it is known that the concentration is low, but the precise concentration is unknown.
	6. Quality of instruments	++	Both ELCO and PATS are frequently used in air quality studies with a focus on biomass burning (Chowdhury et al., 2012; Kumar et al., 2015; Leavey et al., 2015; Ochieng et al., 2016; Pennise et al., 2009; Rosa et al., 2014). Curto et al. (2018) found correlations of 0.82-0.89 between ELCO and a reference instrument, and intra-correlations of 0.8-0.93, under field circumstances. Pillarisetti et al. (2017) report an R^2 of 0.99 between the PATS and a reference instrument under controlled circumstances, R^2 of 0.9 between PATS and a reference instrument and intra-R^2 of 0.94 under field circumstances. For PM2.5 with the IQAV, Massen et al. (2018) found a correlation coefficient with a reference instrument of 0.97. For CO_2, Petersen et al. (2018) found a measurement uncertainty of <50PPM, given instruments are calibrated for temperature influences (which is the case for a -10 to 40^0C range). Based on this, the quality of the instruments is deemed adequate.
Validation of data	7. Identification potential sources of error	+	To prevent instrumental errors, the procedures necessary to start and end the instruments were conducted by the instructor. Students collected and returned the instruments while the instruments were running. The instructor retrieved the data from the instrument. To prevent errors during the measurements, students had to follow the protocol described in this table, row 3, which included guidelines like 'keep the instrument stable on a representative place'. Next to this, there are pollutant-specific sources of error: the CO_2 sensor is sensitive to breathing (for which the students were warned beforehand); in PM measurements, errors can arise when aerosol is deliberately created; for CO measurements, no such manipulation is possible.
	8. Identification of questionable data	++	If the instructor observed unexpected peak values, the students were asked for an explanation. For PM, one group deliberately blew dust in the sensor, so their data cannot be considered reliable (scenario 4F). For CO2, some groups recognized that, at certain moments, someone was breathing close to the sensor. Removal of values outside average+2*std for CO_2 results in a more than 10% average change for two 5A measurements and one 5E datafile. After being aware of these problems, the instructor could confidently prune the data.
	9. Validating by multiple measurements	+	Given the limited availability of instruments, validation by multiple measurements (same time and place) was not done. However, in the indirect quality assessment, discussed later in this article, the data was validated by comparing it with data from similar studies described in the literature.
	10. Peer review	-	Peer review was not part of the course.
Experts	11. Access to experts	++	The instructor has conducted research as part of his MSc study in the field of indoor air pollution, and has been employed as air quality consultant in the Netherlands for 5 years. There were 15 consultancy hours per class (especially during the weeks when the students were working on their plan and report), all groups received written feedback on the measurement plan and report, and for most of the groups this feedback was explained orally.

Table 4. Evaluation of the project versus best practices for reaching educational goals, with a qualitative score (S)

	Best practice	S	Score explanation
Link to curriculum	1. Match of topic with curriculum	+	For the WSEE and MHD students, the topic air quality was a minor component of their curriculum.
	2. Verify knowledge claims	++	In the lectures, several aspects of air quality have been discussed. In the project, the students could empirically verify the presence of different pollutant sources, and their relation to the concentrations and variations on a local level.
Inquiry based learning	3. Use realistic cases	++	The cases were related to relevant and recent air quality issues prevalent in Arba Minch, because the students selected the scenario themselves, from their environment.
	4. No authoritarian answers from the instructor	++	Although the students sometimes demanded an authoritarian (i.e. clear and straightforward) instruction style, the instructor deliberately chose to let the students own the research: i.e. all choices they made were their responsibility for which they needed to have good reasons. For example: students asked "do we need to include quarterly-averages?", the instructor answered: "if you have a good reason to include quarterly averages in your results, you need to include it".
	5. Expose to variety of instructions and methods	++	The course consisted of lectures, quizzes, consultancy hours, computer lab practice, practical instructions, and written and oral feedback. Students could use three different measurement instruments, with different options for measurement frequency, and could make different decisions for all specific components of their measurement conduction.
	6. The whole research process	++	The students were asked to follow the full research cycle. See **Table 3** row 1 for more details about training, & how research cycle was addressed in project.
Student motivation	7. Access to expert	++	The students had regular access to an expert. See **Table 3** row 11 for more details.
	8. Instructor should give positive and corrective feedback.	++	The students got written and oral feedback from the instructor on their measurement plan and measurement report. Students got their document, annotated with comments from the instructor. Most groups came to the consultancy hours to ask for oral explanation of the comments. Positive feedback was incorporated in the lectures and these consultancy hours, in which the instructor appreciated students' participation and encouraged them to make the best of it.
	9. Show the outcome of the students' work in a larger context	++	From the start of the project it was told to the students that their measurement results are especially of added value in Ethiopia, due to low availability of measurements, and would be used by the instructor to identify urgent air quality issues in Arba Minch. Furthermore, groups could submit photos of their measurements for the website www.arbaair.org, and some of their results were presented on that website.
	Students own the research	+	The groups of students had to select an air quality problem in Arba Minch and create their own RQ. They were also fully responsible for the next phases of the research cycle. However, the instructor observed two possible threats to student ownership: (1) When students work in groups, often some members take the lead, and the rest follows. This makes only some of them the owner. (2) Some groups submitted a poor measurement plan in the first round. The corrective feedback of the instructor offered the students a similar, but more relevant/feasible scenario. For some groups this may have suggested that not the students, but the instructor owns/controls the research.
Practical skills	10. Develop an RQ	++	As indicated above, the student groups made their own RQ. Poor RQs were revised based on corrective feedback.
	11. Peer review	-	Students did not review each other's work (similar to **Table 3** row 10).
	12. Present the research process and findings	+	Presenting the research was optional, for 5 bonus points. This was introduced at the end of the semester, resulting in little preparation time for the students. No feedback was given on the presentation skills, so students were only partially trained in this skill.

The SS project was evaluated based on those three points (*data quality*, *knowledge gap*, and *problem for the community*). For the analysis, all scenarios, except scenario 4F, were considered. Scenario 4F was left out of the analysis due to disruption of the measurements. For two datafiles of scenario 5A and one datafile of 5E, all values higher than the average+2*standard deviation (SD) were left out of the analysis, as these values were caused by breathing close to the sensor.

Evaluation of the data quality

To evaluate the *data quality*, measurement results were compared to reference values: measurement results from reference literature, or literature that is comparable to some extent. Comparison was conducted for three parameters: (i) the average of a scenario was compared to R_{Avg}±R_{Std}, or, if R_{Std} was lacking, the range of R_{Min} to R_{Max}; (ii) the average of a single measurement was compared to the range of R_{Min} to R_{Max}; and (iii) the standard deviation of a single measurements was compared to R_{Std}. Different values were reported differently in different studies. In some studies, standard deviations based on the variation within a measurement ('within measurement') were mentioned. In others, standard deviations were based on different measurements ('over measurements'), which obviously were smaller than 'within measurements'. The student's data analysis only included the higher standard deviations (i.e., within measurements). Measurement results were evaluated as *quality data* if the averages fell within the range of reference values, and standard deviations were lower than R_{Std}'s.

Evaluation of the knowledge gap

To evaluate the *knowledge gap* for the different scenarios, literature on similar situations (reference literature) was reviewed. A knowledge gap was operationalized as either the absence of reference literature, or a large variation within reference literature (implying a large influence from local circumstances, i.e. a knowledge gap for another spatial setting). Variation was considered large if, for the values of the reference literature (reference values): (i) the reference standard deviation (R_{Std}) was higher than 0.5*the reference average (R_{Avg}), or (ii) the range of reference values from minimum (R_{Min}) to maximum (R_{Max}) ($R_{Max}-R_{Min}$) was higher than 5*R_{Std}. For R_{Min} and R_{Max}, only averages of full measurements (not values within measurements) were considered. All reference values are shown in **Appendix A**.

Evaluation of the problem for the community

To evaluate the *problem for the community*, the measurement results were compared to guideline values (GVs). Because there were different GVs, measurement results were calculated as a percentage relative to the relevant GV. For each scenario, a highest resulting percentage was presented. Scenarios were considered a problem for the community (worth investigating) if the resulting percentage was higher than 50%. Calculated percentages for PM2.5 and CO_2 were corrected for assumed background concentrations (17 μg/m^3 for PM2.5 and 418 PPM for CO_2 (Dingemanse, personal communication, July 17, 2020); i.e., a measurement result of 418 PPM relative to the GV of 1,000 PPM was not 42%, but 0%. Instead, a measurement result of 709 PPM was considered as 50%). GVs for CO were 87, 52, 26 and 9 PPM for time averages of respectively 15 minutes, 30 minutes, 1 hour and 8 hours (Environmental Protection Authority, 2003); similar time averages from measurement results were used for comparison.

For PM2.5, the World Health Organization (WHO) gives GV's of 25 and 10 μg/m^3 for time averages of respectively 24 hours and 1 year (World Health Organization, 2006); the average PM2.5 concentration of a single measurement was translated to a 24-hour average based on a likely duration of the respective circumstance (scenarios 2C, 2D, 3B, 4D, and 4E: 1 hour; scenarios 4B and 4C: 8 hours), and the assumed background concentration. For CO_2, a GV of 1,000 PPM was based on advice with respect to indoor air quality and ventilation (OSSTF, 2020); the average of a single measurement was used for comparison.

Data Processing and Availability

All measurement data was processed with Python version 3.7.9 (Python Core Team, 2020), and all graphics were created with the Python library Matplotlib version 3.3.2 (Hunter, 2007).

The data generated and/or analyzed during the current study (project instruction documents, air quality measurement data and Python scripts) are available in the OSF repository, https://doi.org/10.17605/OSF.IO/C89X4.

RESULTS

Best Practices for Reaching Scientific and Educational Goals

Table 3 and **Table 4** present the evaluation of the project for respectively scientific and educational goals. As can be seen in the tables, the case study scored well with respect to the best practices. Of the 24 best practices, 15 received full score, while 7 received a partial score, and only 2 were fully absent.

Scientific Contribution of the SS Project

Data quality

Figure 1 shows the range of literature reference measurements and the student measurements. Reference values were based on **Appendix A**. Measurement results are shown only for the scenarios, for which reference values could be obtained from literature. Of the 20 *scenario averages*, three (4A, 4D, and 5D) were outside the range of R_{Avg}±R_{Std}, while two of those, and another one (2C, 4A, and 4D), were outside the range of R_{Min}-R_{Max}. For scenarios 2C and 4D an explanation for the deviation could be given (see **Appendix A**). Only 2 scenario averages were likely unreliable, while 11 were within range of reference values, 2 were outside range with explanation and 5 could not be validated due to lack of reference values.

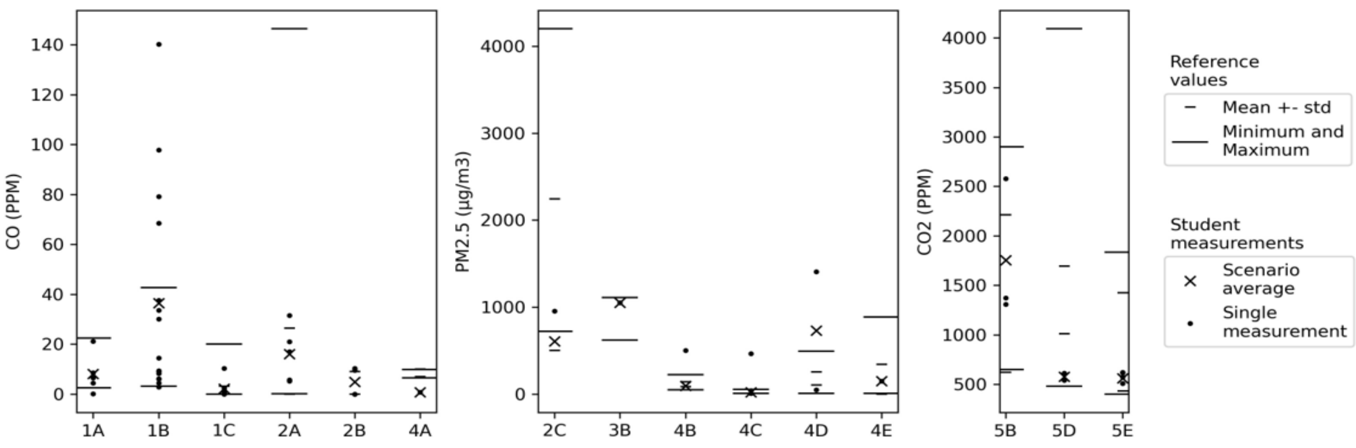

Figure 1. Range of literature reference values (RAvg±RStd and/or Rmin-Rmax value), and student measurement results (average per scenario and single measurement averages)

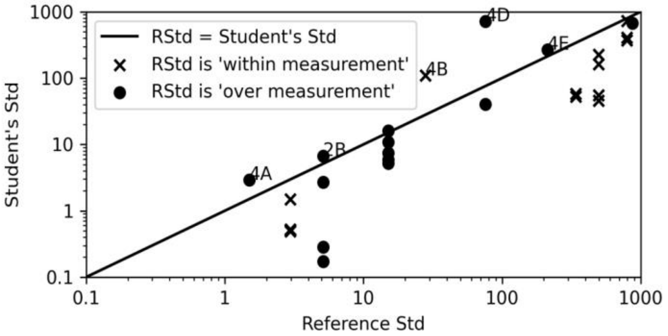

Figure 2. SDs of student measurements versus RStd

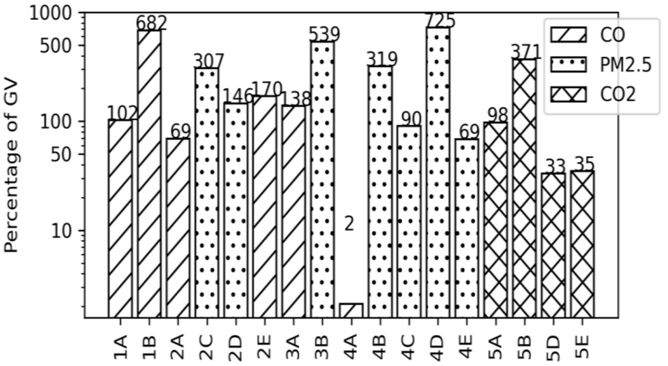

Figure 3. Highest measurements for scenarios relative to guideline values

Of the 63 *single measurements*, 9 were outside the range of reference measurements (1A: 1; 1B: 5; 2C: 1; 4A: 1; 4D: 1). For scenarios 1B, 2C, and 4D, an explanation for the deviation could be given (see **Appendix A**). Only 2 single measurements were likely unreliable, while 40 were within range of reference values, 7 were outside range with explanation and 14 could not be validated.

Figure 2 shows the standard deviations (SDs) of the single measurements versus the SDs of reference measurements. Of the 63 single measurements, only five had higher SDs than the reference values. Of these, four were compared to SDs over measurements (see **Appendix A**). Only 1 SD of single measurements was likely unreliable, while 21 were within range of reference values, 4 were outside range with explanation and 37 could not be validated.

Problem for the community

Figure 3 shows the highest measurement for each (relevant) scenario, relative to the respective guideline value. Scenarios 1C, 2B, and 5C were not considered as their comparison to GVs was not relevant (results are low due to the object of those scenarios' measurements). 3 of the 17 scenarios had values lower than 50% of the guideline value, 3 between 50-100%, and the remaining 11 exceeded the guideline value. Among those with the highest percentages were restaurant kitchens (1B), coffee ceremony (2C), waste burning (3B), bus station (4B), generators (4D), and dormitory concentrations (5B).

Knowledge gap

Table 5 shows that for 18 out of 20 scenarios there was a research gap. For 9 scenarios there was a research gap, because no other studies had been done on this situation (NR). For the other 9 scenarios there was a research gap because the studies show measurements with large variations (LV), indicating that local measurements must be conducted to get insight in a local situation. For two scenarios there was no research gap (-), indicating that the air quality situation of the investigated phenomenon can also be predicted on the literature. For them, air quality measurements were not strictly necessary.

DISCUSSION

Discussion of the SS Project

A student science project can be a solution to both scientific and educational challenges in a low-income country such as Ethiopia. The evaluation of an SS project on Arba Minch University revealed that conducting an SS project is feasible, as most practices for reaching scientific and educational goals were met. Not all best practices were executed, most notably peer review. Peer review leads to a higher understanding of data quality by students (Mitchell et al., 2017), and review and rating between members leads to enhanced data quality as well (Hunter et al., 2013). Only after doing this research ex post the instructor is inspired to apply this (and other missed best practices) in the future.

Similarly, the provided overview of best practices and the in-depth insight in this case can offer inspiration for other lecturers at universities in low-income countries for the introduction of practical assignments in combination with conduction of research. The wider this is taken up, the deeper the connection with the curriculum is created, benefiting educational goals (Zoellick et al., 2012).

As access to experts is an important part to a successful SS project (Boersma & Vroom, 2006; Evans et al., 2001; Freitag & Pfeffer, 2013; Lawless & Rock, 1998), successful execution depends on the expertise, motivation and available time of the instructor. The two-fold goal (scientific and education) requires input from both the expert and the curriculum (Zoellick et al., 2012), and implies distinct roles for a scientist and a teacher (providing expertise and providing access to it) (Peker & Dolan, 2012). To make a fulfilment of these roles, with enough motivation and time, more likely, cooperation between different staffs and different courses is advisable.

The evaluation of this project also revealed that an SS project on a university in a low-income country can have relevant scientific contributions. For various other countries, scientific contributions are already proven through the mere fact that citizen science projects have resulted in several scientific publications (Mitchell et al., 2017). Data from such projects is 'largely valuable and (…) errors (…) can generally be fixed or accounted for.' (Aceves-Bueno et al., 2015, p. 503). A main challenge is the scientific use of gathered data (Conrad & Hilchey, 2011).

The data collected in this SS project is used as input to distinguish priority areas in air quality research (article under submission), and data is publicly available at: https://doi.org/10.17605/OSF.IO/C89X4.

Table 5. The research gap per scenario: no reference studies (NR), large variations (LV) or no research gap (-)

	Scenario	Gap	Explanation
Restaurant	1A 1B 1C	NR NR NR	For restaurant air quality, with dominant use of biomass, no reference studies can be found. Some studies had such kitchens as subject, but no air pollutant measurements were conducted (Juntarawijit & Juntarawijit, 2017; Mahembe et al., 2010; Singh et al., 2018). Within restaurant visitor areas, studies are related to smoking (for example, Konstantopoulou et al., 2014; Williams Jr et al., 2014), or to Chinese cooking styles, cooking oils & deep frying (Lee et al., 2001; Lee et al., 2002; Zhao et al., 2010). Only one study conducted measurements in a restaurant with biomass fuel (a charcoal barbecue restaurants), both in visitor areas and kitchens, but in these restaurants also gas appliances are used (Zhang et al., 2017), i.e. no dominant use of biomass as fuel, as was the case for scenarios 1A through 1C.
Household	2A	LV	Several studies have been conducted within household kitchens during use of biomass fuels. Studies with CO measurements during cooking, with maximum averaging periods of 2 hours are reference studies (Clark et al., 2010; Khalequzzaman et al., 2011; Leavey et al., 2015; Mukhopadhyay et al., 2012). There is however large variation ($R_{std}>0.5*R_{avg}$).
	2B	NR	In relation to electrification of the kitchen, two studies with measurements are focused on a longer period than only the cooking period (Barron & Torero, 2017; Rollin et al., 2004), while scenario 2B considered cooking only.
	2C	LV	The Ethiopian coffee ceremony inside a house has been subject of one pilot study (Keil et al., 2010). There is however large variation ($R_{std}>0.5*R_{avg}$).
	2D 2E	NR NR	For an outdoor coffee ceremony or outside cooking on charcoal, no reference studies could be found.
Wasteb.	3A 3B	NR NR	For waste burning, no reference studies could be found. The few studies that are concerned with concentrations from open waste burning, conducted measurements at a larger distance (Baalbaki et al., 2018; Cheng et al., 2009; Sivertsen, 2006).
Ambient	4A 4B	- LV	In different bus stations across the world measurements have been conducted (Cheng et al., 2009; Razif & Abib, 2006; Salama et al., 2017). For PM2.5, there is a large variation ($R_{max}-R_{min}>5*R_{std}$).
	4C	-	Concentrations at roadsides/outside bus stations are monitored across the world. A study in which both a bus station & background concentrations were measured (Jamriska et al., 2005) is used as reference study.
	4D	LV	For generators, different studies have been conducted (Giwa, 2019a; Giwa, 2019b; Oguntoke & Adeyemi, 2017), in which large variations are found across age, fuel and size ($R_{max}-R_{min}>5*R_{std}$). Diesel generators emit more than gasoline generators, and a higher power output generally also leads to higher emissions.
	4E	LV	For smoking, different studies have been conducted. Some of these studies are used as reference studies (Brauer & Mannetje, 1998; Williams Jr et al., 2014). Variations are large ($R_{std}>0.5*R_{avg}$).
Ventilation	5A	NR	No reference studies with measurements are found for libraries.
	5B 5C	LV LV	For dormitories, several measurements have been conducted for an MSc thesis (Jenkins, 2018). Variations are large ($R_{std}>0.5*R_{avg}$). Measurements outside the dormitories simply served for comparison with scenario 5B, hence the knowledge gap classification is similar.
	5D	LV	For classrooms, several studies have been conducted (reported by Soomro et al., 2019). Variation is large ($R_{max}-R_{min}>5*R_{std}$).
	5E	LV	For restaurants, reference studies can be found (Akbar-Khanzadeh et al., 2002; Zhang et al., 2017). Variations are large ($R_{std}>0.5*R_{avg}$).

Limitations and Recommendations

The feasibility was evaluated based on a comparison with best practices. Evaluation of these best practices is ultimately a discipline-related matter. For disciplines other than local air pollution, other types of instruments, data quality goals and curriculum requirements might lead to another weight of the different best practices. While this study showed the feasibility of *an* SS project, this does not necessarily mean that *any* SS project for *any* discipline is feasible. This study has however provided a framework for evaluation of the feasibility of SS projects. Experts on public universities in low-income countries can set up SS projects in their respective disciplines and can study the feasibility of their specific project with this framework.

The broad scope of this study forced concessions on evaluating the scientific contribution of the students' work. The operationalization of the knowledge gap, data quality and the problem for the community are general. For aggregated citizen science data, Aceves-Bueno et al. (2017) find insufficient levels of accuracy, but this data might prove of higher quality if the comparison is conducted on a higher detail (Specht & Lewandowski, 2018). A more detailed check of each scenario could enhance the assessment of the scientific contribution (e.g. the relevance of electrification (Barron & Torero, 2017), studying specific variables influencing the different concentrations (Baumgartner et al., 2011; Kumie et al., 2009) such as ventilation (Zhang et al., 2015), stove types (Hu et al., 2014), or seasonal variations (Ni et al., 2016) to mention a few). Naturally, SS projects in other disciplines would require other checks with respect to their scientific contribution.

Lastly, next to evaluating the scientific contribution, there is a need for evaluating educational contributions of the SS project. While meeting educational best practices suggests positive educational contributions, this hypothesis has not yet been tested in the context of a public university in a low-income country like Ethiopia. Methodologies used for such an evaluation are pre- and post-intervention surveys, tests, interviews, questionnaires, or even observation (Houseal et al., 2014; Lasen et al., 2014; McLaughlin et al., 2016; Mitchell et al., 2017; Sadler et al., 2009). All these methods need to be planned together with the SS project.

CONCLUSION

This study evaluated the feasibility and scientific contribution of a Student Science project on a public university in a low-income country. With respect to feasibility, it is found that the best practices for successful SS-like projects, education and scientific-wise, could be executed in the case of Arba Minch University (Ethiopia). As for scientific contribution, it is found that most student groups gathered quality data, related to a knowledge gap which is a problem for the community. Therefore, we can conclude that an SS project at a public university, in the context of a low-income country, is feasible and can lead to a useful scientific contribution. This SS project created more insight in the Ethiopian air quality situation, a field for which not yet many studies and funds are available, while, at the same time, it offered students training in inquiry-based thinking and other practical skills. It is recommended that public universities in low-income contexts implement part of their curriculum goals in such projects.

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APPENDIX A

Reference values from reference literature, or literature some extent comparable to the respective scenario

	Reference values R_{Avg} (R_{Std}) [R_{Min}-R_{Max}]	Reference study	Remark
Restaurants (1A visitors PPM CO; 1B kitchen PPM CO; 1C outside kitchen PPM CO)			
1A	12.3 [2.6-22.5]	(Zhang et al., 2017)	Kitchens with mixed gas and charcoal (barbecue) appliances; higher values in dedicated biomass fuel kitchens might not be invalid.
1B	21.1 [3.2-42.6]	(Zhang et al., 2017)	
1C	0.2 (2.97) [0-20]	(Leavey et al., 2015)	Reference study is not outside restaurant kitchens, but outside household kitchens. Mean and std are geometric.
Households (2A kitchen biomass PPM CO; 2B kitchen electrified PPM CO; 2C coffee ceremony inside $\mu g/m^3$ PM2.5)			
2A	7.9 (11.2)^{y} [0.1-54] 7.8 (15.1)^{y} 22.3 [1.3-146.4] 7.5 (5.75)^{y} 11.4 (15.1)^{y} [0.1-146]	(Clark et al., 2010) (Khalequzzaman et al., 2011) (Leavey et al., 2015) (Mukhopadhyay et al., 2012) Values used	
2B	3.9 (5.1)^{y}	(Barron & Torero, 2017; Rollin et al., 2004)	50-66% reduction in electrified vs unelectrified kitchens. Values based on 2A*0.34.
2C	1373.5 (870)^{y} [<720-4200]	(Keil et al., 2010)	Reference values are in PM4, and lower limit of measurement method is 720 $\mu g/m^3$. Lower student values of PM2.5 might not be invalid.
Waste burning (3B $\mu g/m^3$ PM2.5)			
3B	[622-1110]	(Sivertsen, 2006)	Reported values not based on measurements, but on modelled PM10 values and the ratio between reported PM2.5 and PM10 emission values.
Ambient (4A Bus station PPM CO; 4B Busstation $\mu g/m^3$ PM2.5; 4C Outside bus station/roadside $\mu g/m^3$ PM2.5; 4D Generator $\mu g/m^3$ PM2.5; 4E Smoking $\mu g/m^3$ PM2.5)			
4A	8.5 (1.5)^{y} [6.5-9.8]	(Salama et al., 2017)	Values from Salama based on the 'parking' measurements.
4B	163 (28) [121-223] 127 [78.5-182] 55.2 [49-75] 115 (28) [49-223]	(Y.-H. Cheng et al., 2011) (Razif & Abib, 2006) (Salama et al., 2017) Values used	Values from Salama based on the 'parking' measurements. PM10 values from (Razif & Abib, 2006) changed to PM2.5 based on ratio 0.49 from (Y.-H. Cheng et al., 2011; Salama et al., 2017)
4C	[7.6-55.8]	(Jamriska et al., 2005)	Ratio of background to busstation concentration 1:4-1:10. Calculated values based on 5b/10-5b/4
4D	374 (75.6)^{y} [221-492] 83 (54.2)^{y} [26-309] 85.9 [7.9-173] 181 (75.6)^{y} [7.9-492]	(Giwa, Nwaokocha, & Adeyemi, 2019) (Giwa, Nwaokocha, & Samuel, 2019) (Oguntoke & Adeyemi, 2017) Values used	Generators in (Oguntoke & Adeyemi, 2017) are <25 kVA and in (Giwa, Nwaokocha, & Samuel, 2019) gasoline and <7.2 kVA. Generators in (Giwa, Nwaokocha, & Adeyemi, 2019) are up to 500 kVA and diesel, however the mentioned instrument's upper limit is 500 $\mu g/m^3$. Higher values of PM2.5 might not be invalid[a].
4E	124 (95)^{y} [11-253] 131 (213)^{y} [9.7-887] 127.1 (213)^{y} [9.7-887]	(Brauer & Mannetje, 1998) (Williams Jr et al., 2014) Values used	**EXPLANATORY NOTES.** For multiple studies, the average R_{Avg} is based on equally weighed averages. As R_{Std} the highest reported SD in any of the reference studies is used. Some studies report Stds based on the fluctuation within a measurement, while others report SDs based on the variation over different measurements (marked with^{y}). For R_{Min} and R_{Max}, the lowest and highest value (over different measurements) are used.
Ventilation (5B Dormitory PPM CO_2; 5D Classroom PPM CO_2; 5E Restaurant PPM CO_2)			
5B	1416 [650-2900]	(Jenkins, 2018)	
5D	1351 (341) [478-4093]	(Soomro et al., 2019)	
5E	1234 (495) [618-1835] 623 [400-890] 929 (495) [400-1835]	(Akbar-Khanzadeh et al., 2002) (Zhang et al., 2017) Values used	

Note. [a]Higher PM2.5 emissions can be expected from diesel-powered (vs gasoline) and higher power generators