Implementation of a Novel Educational Course to Teach 3D Printing, Circuit Design, and Programming to PhD Candidates in Nigeria

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⁴ Trend in Africa

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Objective: This paper aims to describe the need for a course that teaches open source principles, 3D printing, and programming to PhD students in Africa. It also describes the implementation of the course in detail so that others may conduct similar programs.

Introduction

The primary goal of the “Open Labware: 3D Printing Your Own Lab Equipment” workshop organised by TRoND (Teaching and Research in Natural Sciences for Development in Africa) is to help the development of local expertise and capabilities of researchers and teaching faculty, and therefore to add momentum to academia in the African continent. Research on the African continent is very limited, given that all of Sub-Saharan Africa contributes 0.8% of worldwide research and development expenditure annually¹. Three primary areas for improvement were identified:

1) Increased Interdisciplinary Interaction

Data sharing and the open-source movement have enabled larger, more robust data sets to be collected. Moreover, the data can be assembled in less time and with a greater variety of populations and improved reproducibility².

However, even with so many benefits, there are a number of barriers to improved data sharing. Specifically in Africa, these concerns include “loss of control once data is shared; sub-optimal gains to those who create and manage data; undue advantages to more technologically resourced contexts because of technological imbalances and skill-sets in their favor; and technical issues including data quality, inter-operability, and risks of misinterpretation due to unfamiliarity with data-originating contexts”³⁻⁵.

On a more personal level, many researchers were interviewed for one article examining African researchers’ attitudes toward data sharing and one stated “we have issues with sharing data. These days the thing that has come up all over the world is ‘open access’. You cannot collect data using your own resources and put it on open access”⁵. The technical means to share data are in place and widely available. However, there are clearly cultural barriers to sharing data.

A major goal of this educational course is to shift this paradigm and educate about the many benefits to participating in the open-source movement, and to encourage individuals to engage in it. Our previous experience with the Open Labware Workshop showed that although participants were able to learn the new content and apply it during the program, the development of equipment itself could be greatly optimised if they established partnerships and collaborations with other researchers with engineering backgrounds. Such partnerships would be beneficial for both parties, as engineers could provide the technical expertise, and know which building methods could be better applied in each case, and natural science researchers could bring ideas

of what to implement in a new piece of laboratory equipment. Development and production of scientific equipment domestically in Nigeria and other African countries would represent a paradigm shift for the region, as a large portion of scientific equipment used in the African continent is imported from overseas⁶.

2) Providing Access to Equipment

Consistently throughout the 70 group applications that TRenD received for the course, teams mentioned lack of equipment as their primary reason for applying to the course. Most of the participants had research projects in mind that required additional equipment to complete. The reasons behind the lack of equipment are multifactorial, and include no supply chain, exorbitant cost of equipment and shipping, lack of consumables, and broken/missing components. While some organizations donate research equipment, it is often either non-functional, or there is no training on its use so it remains packaged without the ability to utilize it⁷. Furthermore, this model of support is not sustainable⁸. Though data is sparse, a recent survey published by Seeding Labs showed that 76% of African researchers stated that their institution did not have the proper equipment for current research projects, and 93% reported not having equipment for future research endeavors. Unfortunately, 83% responded that the grants that they apply for explicitly prohibit purchasing equipment with funds or are insufficient to purchase needed equipment.

The expiration of patents on FDM 3D printing technology and the fact that the production of electronic circuits is still following Moore's law (where electronic devices' prices drop at regular intervals)⁹, has allowed an expansion of access to low-cost, high-accuracy production. Further, the open-source movement has fostered the development and made plans freely available of many critical pieces of laboratory equipment that have traditionally been cost-prohibitive to obtain. Combining the emergence of these two phenomena, we were able to provide access to many pieces of equipment that have traditionally been unobtainable in developing countries through more sustainable means. Through access to this equipment, PhD students and academics were able to complete research that was previously impossible, and do so with higher scientific standards.

3) Providing Knowledge of Programming and Circuit Design

While some research equipment solely required 3D printing (pipettes, micromanipulators etc.) much of it also needed electronic components to function. Integration of computer-assisted research set ups allows many experiments to be more scientifically sound, as measurements and timings could be much more accurate and instantly recorded. Thus, teaching the Arduino programming language and circuit building with Arduino boards was vital to the project. The vast majority of the participants in the course had no previous programming or circuit building experience. This is likely secondary to a lack of early exposure. In South Africa, for example, only

22% of primary schools have computers¹⁰. This lack of access to computers has been shown to be directly correlated with how rural an individual's school is. Moreover, those from more rural areas were found to have more interest in computer-related professions¹¹. Another study assessing medical students found that fewer than 60% were able to perform core computer skills. However, after a 5 hour tutoring session, student's competency scores doubled on average¹². Teaching fundamental programming and electronics was crucial to giving the participants the skills necessary for creation and repair of laboratory equipment, and hopefully manageable within the time allocated for the workshop given the success of other similar computer education courses in the region.

Assessment

In order to assess the success of the course in achieving the aforementioned goals, the participants were surveyed with regards to their opinions and knowledge of the open source movement, production of labware with 3D printing, and computer programming. Further, extensive documentation of the projects that each group produced was recorded and summarized in this paper.

Methods

Location

The workshop was held at the Department of Physiology at the University of Ibadan in Ibadan, Nigeria. The University is one of the best ranked institutions in the country and in the continent, and Ibadan is the third largest city in the country and home to more than 10 different institutions of higher education, making it a place with strong academic tradition. Moreover, participants from the first iteration of this course, held in Addis Ababa, Ethiopia in 2015 are associated with this institution and participated as local organizers and teaching faculty.

Selection of Participants

Eight teams of 3 individuals each were selected, totalling 24 individuals. Twenty-two were PhD students in physiology, biology, and neuroscience, and 2 were professors. There were 2 groups from University of Ibadan, Nigeria where the course was hosted and 1 from each of the following countries: Democratic Republic of Congo, Germany, Ghana, Kenya, Rwanda, and Uganda.

A call for applications was published on January 15th 2017 and was open until February 28th 2017. The call was advertised via online channels: Email lists (composed of partner institutions, supporting foundations and alumni), TReND's website and social media channels (Twitter, Facebook, Instagram). Seventy two teams applied to the course from 12 countries. The applications were then placed into a central repository

with access granted to all 12 course faculty. They were given a score of 0-5 on a likert scale (0 being the minimum and 5 the maximum) by each course facilitator to assess the group's background knowledge, project idea, and previous experiences. All facilitator scores were then averaged and a cohort of top-rated groups was obtained. The facilitators then chose the top-rated groups that produced the most diverse group possible based on gender, country of origin, and area of study.

Selection of Course Faculty

Instructors consisted of 12 individuals. Half were faculty and students from the University of Ibadan. The remaining six faculty were based in Germany, Chile, Sudan, and the US. From the local faculty, two had participated in the 2015 implementation of this course in Ethiopia.

Course faculty was selected based on their knowledge of the open source hardware movement, 3D printing, circuit building, and programming. In order to create a sustainable development model, faculty was also chosen based on their home institutions. In order to foster sustainability of the program, more than half of the faculty originated from African universities. The majority had long term positions or planned to remain in the University of Ibadan for the next few years. Our rationale was that this approach would create a small cluster of local experts, that could keep pushing participants forward, create their own independent projects, and serve as an example for other universities to follow suit.

General Workshop Design

The course ran 6 days per week for 2 weeks from June 26 to July 08, 2017. The daily structure was divided into two morning sessions (8:00 to 10:30 and 11:00 to 12:30) and two afternoon sessions (14:00 to 15:30 and 15:30 to 17:30). In the first week, each morning session started with a brief theoretical lecture (approximately 25 minutes) on Arduino and electronics, followed by practical exercises. The afternoon sessions followed the same pattern, but the theoretical explanations were on 3D printing topics. Each group of 3 students was encouraged to work collaboratively with the other groups. This method of both lecture- and collaborative-based education was utilized because each type has advantages and disadvantages. One study, for example, found that participants learned better in a collaborative environment, but preferred lecture-based education¹³. Two sponsored coffee breaks next to the work-areas were provided, and lunchtime was ~1.5 hours. Each day usually concluded around 18:00, depending on the progress.

Week 1 - Morning Sessions - Arduino and Electronics

The Arduino sessions started on the morning of day 2, when each participant received one "Arduino Starter Kit" containing the Arduino board, different sensors (temperature, light, tilt, push buttons), actuators (motors, LEDs, buzzers), and other

building components (jumper wires, resistors, capacitors) to create electronic circuits. After brief theoretical explanations, participants were guided through a series of hands-on exercises, where they built small electronic circuits and wrote pieces of code that would control the built circuit. These exercises were created to be elementary building blocks that grew in complexity and could be reused, adapted, and added to other blocks. This modularity was an important preparation for the second week of the course, focused on actually building equipment, as it gave participants enough skills to start writing computer code for their projects right away. During the exercises, faculty was available to answer questions and help troubleshoot circuits that did not work. Participants were encouraged to spot their own mistakes and to consult the book provided with the Arduino kits, to search for solutions online, as well as to seek answers with fellow participants (Figure 1).

Figure 1

Arduino and electronics session. A - Brief content explanation done by local staff. B - Two groups working together to understand the material. C - Assembling a circuit from the Arduino kit. D - A completed circuit from the exercise manual.

Week 1 - Afternoon Sessions - 3D Printing and Modelling

Following a general welcome and introductory lecture on Open Labware on day 1 each group was provided with all off-the-shelf components to build their own Prusa i3 3D printer. This design was chosen because it is open-source, and one of the most popular designs, making troubleshooting online easier. The components included a metal frame, 3D printed chassis components, stepper motors, bearings, circuit boards, leads, electronic components, hot-end, hand-tools as well as printed assembly and user

manuals (Figure 2). One additional complete kit was brought, totalling 8, to use for spare parts. Faculty was available at all times to answer questions and help tricky assembly steps, usually with 1 faculty member assisting 1-2 groups at a time. Emphasis was put on self-sufficiency of students, such that help was offered upon request or if instructors noticed that steps were being carried out incorrectly. Most groups progressed at approximately the same rate, often learning from observing each other's constructions. In addition, at times individual components would be sub-optimally shaped or broken such that groups had to learn how to identify and repair a wide range of issues that can occur with their 3D printers (Figure 3).

Figure 2

Materials for the course, 3D printer parts and electronics kits. A - All printer and electronic components laid out before the course start. B - A group with their materials.

Figure 3

Groups assembling their 3D printer. A - A group assembling the frame. B - Putting together the hot end. C - Wiring the electronics. D - The completed printer.

Overall, the didactic approach taken demonstrably led to a deep understanding of not only the basic principles of 3D printer design and assembly (see Results section below), but also an ability to understand and meet previously unencountered problems – a fundamental prerequisite for constructive use of 3D printers in the absence of immediate expert help.

They were introduced to online repositories and guided to download predesigned models useful for the laboratory, which allowed them to grasp the capabilities and limitations of their machines, as well as to perform the last necessary fine-tuning. The final part of the printing module consisted of lectures in 3D modelling using the open-source software “OpenSCAD”. This was a lightweight package available for free and backed by an active online community, that allowed newcomers to quickly generate simple shapes, as well as clone and modify designs already available online in repositories like Thingiverse and NIH 3D print exchange. Moreover, the package is code-based stressing the usefulness of learning computer programming.

Open Door Day

On July 1st faculty and participants held an “Open Door Day”. The university community, three local high schools, representatives from the local industry and the

general population were invited to visit our lecture hall and talk about 3D printing, circuit design, and general open-source principles. Our students talked about their projects, aiming to expose all visitors to new ideas and technologies as well as to create a welcoming environment to foster local collaborations (Figure 4).

Figure 4

Open Door Day. A - One of the faculty members explaining 3D printing to a group of high schoolers. B - Models to demonstrate the capability of 3D printers. C - A facilitator talking to the students about STEM and open source science. D - Students exploring the 3D printed models.

The high school students were welcomed by local TReND Alumni, who explained about the aims and goals of the workshop, as well as how 3D printers work and their applications. Industry was represented by three Nigerian companies, one selling open-source electronics ([Satajanus Electronics](#)), one selling services in 3D printing ([Stampar 3D](#)), and one from biotechnology ([Africa Biosciences](#)). Representatives from different departments of the University were also actively engaged throughout the day. (figure of high school students and open door day)

Week 2 - Working on Projects

The second week was dedicated to the development of hardware projects. Prior to the course each group prepared a small description of a piece of laboratory equipment they wanted to develop, allowing organizers to source crucial parts beforehand and to anticipate what electronic circuits would be necessary. Project development started by a demonstration of open-source hardware repositories and

instructing groups to find hardware that matched or were related to their own in those repositories. After suitable matches were found, participants were encouraged to follow the steps described in the online descriptions and to discuss with faculty/fellow participants in case any modification of parts or code was necessary.

Throughout the week the 3D printers were used to create the structural components of the new equipment (Figures 5 and 6). In addition to designing and building the project, participants were instructed to document all the steps of their builds, with photos and detailed description of the building steps, so that everything could be uploaded to Instructables, a do-it-yourself repository known for its active and welcoming community.

On the last day of the course, the printers were disassembled and packed into the boxes they came in. Most groups detached the z-axis from the y-axis and packed it this way, so as to minimize reassembly when they returned home. Foam was purchased from a local market so that it could be cut to fit the new shape of the printer.

Figure 5

Projects with primarily 3D printed-related components. A - Centrifuge (circuitry contained within box). B - Agitator. C - Micropipette micromanipulator. D - Pipette¹⁴.

Figure 6

Projects with primarily Arduino-related components. A - Passive avoidance setup (3D printed brackets, door track, door). B - Circuit for passive avoidance task seen in figure 6A. It controls the door and electric shock delivery. C - Programmable heating/cooling element for PCR.

Additional lectures on related topics

To inspire students beyond the immediate subject matter and to break the daily routine, we held lectures on a range of related topics, depending on the individual instructor's expertise. These included:

- 1) Fluorescence and Cell Free Biology – Fernan Federíci (Special guest from UC Chile) (Figure 7)
- 2) What Next? Are we done after 2 weeks? – Faborode (Alumnus from 2015 and teaching faculty)
- 3) Open Design – Benjamin Royal, Agustina Palermo, Rebeca Estrada (One of the participating groups from Germany)
- 4) OLABI, an inclusive Brazilian MakerSpace – Rebeca Estrada

Figure 7

Special guest lecturer Fernan Federíci presenting a module on state of the art methods in molecular biology. A - Fluorescence and Cell Free Biology lecture. B - Open source fluorescence microscope used in the module.

Common problems that were encountered in the building and calibration processes were recorded throughout the course. These were then submitted to the distributor of the printer kit to hopefully improve their documentation. Further, the issues were organized into a slide deck with their corresponding solution.

All theoretical course materials and resources were provided to students using Google Drive, and can be accessed at the following URL: goo.gl/XgpJNF.

Results

Improvement of infrastructure – Solar power supply

The availability of reliable, uninterrupted power supply was crucial for the successful completion of the workshop, as 3D printing of complex and large designs can take more than 10 hours and current printers do not allow for procedures to be stopped and then later resumed. Although already advised about the occasional power

interruption at the University campus, the situation during the first days of the workshop was extremely inconsistent, and the sessions had to be constantly stopped for a generator to be switched on, after power went out. This not only broke session fluency, but it also created additional fuel costs. The solution for the problem was to quote and install a system that would generate, store, and supply solar power (Figure 8). With a capacity of ~700W the system could power five printers running in normal mode for one hour, or 3 printers in peak mode (initial heating phase). The location of the system was chosen so it would supply a designated room that housed the printer built in the current workshop by the teams from Nigeria, as well as the one built in Ethiopia by the Nigerian participants in 2015, making it a small workshop for Open Labware design and a place to train students and university staff on prototyping and open source technologies.

Figure 8

Solar panels installed at the University of Ibadan. A - The supplies to create the solar array. B - Demonstration of the solar panels to the class. C - Installation of the solar panels.

Participant interaction and local collaborations

In order to improve participant interaction and local collaborations, the current workshop took new steps concerning participant interaction and the composition of the teaching faculty. Throughout the course, participant interaction was instigated by orienting groups that mastered a certain topic to teach other participants. This led to more practical work from both parties, as well as served to keep all participants at the same learning pace and increased social interaction during and after workdays.

In order to nurture potential collaborations in the development of laboratory equipment and boost support for participants, the number of African researchers present as teaching faculty was increased as compared to the workshop's previous edition, as well as their research field diversity. Out of 10 tutors, 6 were from African institutions; one was from the physics department at the University of Khartoum, and the remaining ones were from the University of Ibadan - 2 from the Physiology Department, and 3 from the Engineering department. With this structure, participants will have enough support for their future projects. Additionally, this group has all the necessary expertises and contacts to start a working group dedicated to equipment development.

3D Printer Building and Calibration

The speed at which each group built and calibrated their machine varied greatly. The quickest group finished in approximately 3 days, while the group that took the longest finished at the end of the first week. While some machines had moments of dysfunction during the second week, they were quickly repaired and were functional throughout the end of the course.

Open Door Day

Students from the electrical and computer engineering departments were very interested in the event, as they could see direct application of the technologies presented to their future academic careers. Moreover, the presence of the technology companies had a positive impact as participants learned where they could source parts for their projects and started conversations for collaborative projects. Overall we received very positive feedback from participants and visitors, perceived by the number of comments and emails received. The organizers estimate ~120 people have visited the event.

End of Program Survey Results

Below are tables with the results of 21 respondents to a survey distributed electronically at the end of the course.

Table 1 - Yes/maybe/no survey questions

Survey question	Yes	Maybe	No
Before the course, had you ever heard about the Open Source philosophy and its implications?	7 (33.3%)	0 (0%)	14 (66.7%)
Do you plan to implement Open Source projects in your research?	19 (90.5%)	2 (9.5%)	0 (0%)
Before this course, were you familiar with 3D printing technologies?	6 (31.6%)	0 (0%)	13 (68.4%)

With access to a 3D printer, do you plan to use it in your research activities?	19 (90.5%)	2 (9.5%)	0 (0%)
Before this course, were you familiar with Electronics and the Arduino microcontroller?	6 (28.6%)	0 (0%)	15 (71.4%)
Do you plan to use electronics and Arduinos in your research?	20 (95.2%)	1 (4.8%)	0 (0%)

Table 2 - Likert survey questions

Survey question	Average (standard deviation)
On a scale of 1 to 10 (1 being minimum and 10 being maximum), how well do you think the topic of Open Source was introduced?	8.2 (1.3)
On a scale from 1 to 10 (1 being minimum and 10 being maximum), how comfortable do you feel with 3D printing	8.8 (1.1)
On a scale of 1 to 10 (1 being minimum and 10 being maximum), how comfortable do you feel with electronics and Arduino?	7.2 (1.7)
On a scale of 1 to 10 (1 being too little theory and 10 being too much theory), please rate the amount of practical work and lectures:	6.2 (2.1)
On a scale of 1 to 10 (1 being too easy and 10 being too hard), please rate the difficult level of following the lectures given	5.3 (2.0)
On a scale of 1 to 10 (1 being too little input, 10 being too much interference), please rate the participation level of the tutors during practicals	7.2 (1.8)

The data show that overall, less than one third of the participants were familiar with open source ideas, 3D printing, and electronics and programming before the beginning of the course. After the two weeks of training, participants rated their comfort with 3D printing as 8.8 out of 10, and comfort with electronics and arduino as 7.2 out of 10. This demonstrates that with a relatively short course, participants can go from unexposed to a technology to competent. Looking forward, 90% plan to utilize 3D printing in their research, and 95% plan to use electronics and arduinos.

Project Creation

Perhaps the most convincing data to support the success of the course are the numerous projects that the groups completed. Upon uploading their projects, the groups were officially moving from passive observers and consumers of hardware development to producers of open-source hardware and active members of a vibrant community by actively helping each other during the finalization of each project. Despite the very

limited time for development, they were able to conclude interesting projects (or at least reach an advanced prototype stage). The student projects can be found at the following links:

3D models uploaded to Thingiverse: <https://goo.gl/GcVuqB>

Project descriptions uploaded to Instructables: <https://goo.gl/XhNuxp>

Conclusion

The data presented here demonstrates that it is possible to bring people from passive technology consumers, who have never been introduced to open source technologies and electronics, to active producers of laboratory equipment and open source knowledge. Moreover, we show that this can be done in a relatively short period of time (12 days) and in a low resource setting, while giving participants the confidence to join the global open source movement for scientific hardware.

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