FIRST ADVANCED OPEN LABWARE WORKSHOP AND RAPID PROTOTYPING SOLUTIONS FOR RESEARCH CHALLENGES IN AFRICA

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ABSTRACT

We report on a workshop based on open source principles to implement innovative solutions for laboratories and science applications in Africa. Specifically, 3D printed designs and electronic circuit designs implemented by different research teams from Africa are highlighted. The advanced open labware workshop enabled teams to develop setups to solve challenges faced in their own laboratories or research environments. The workshop showed that substantial developments could be made within a two week time frame, particularly using rapid prototyping techniques such as 3D printing and laser cutting to accelerate the development of the open labware solutions.

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1. INTRODUCTION

Similar to open software or hardware, open labware entails lab equipment designs that are openly shared and that enable people to build solutions at a very low cost compared to commercial equipment. This movement has resulted in collaborative projects such as Open-Labware.net (https://open-labware.net/) where designs of free and open source hardware and software projects are shared, with focus on scientific laboratory or research settings. A comprehensive review on open labware [1] shows various projects that have been explored, including low-cost microscopes, centrifuges, thermocyclers and waveform generators. These projects cover various areas and are applicable to different laboratories in fields of molecular biology, electrophysiology, fluidics and microscopy, to name a few. A number of articles and open projects are available through channels such as the PLoS Open Hardware Collection (https://channels.plos.org/open-source-toolkit), highlighting the growth of open projects in recent years.

A number of workshops focused on open labware have been held in the past few years to create an awareness of these open principles and projects, with the aim of transferring knowledge and skills to researchers in developing countries. Initial work entailed formulating processes to be able to promote neuroscience education and research in Africa [2], which formed the foundation for the workshops.

The aim of the *First Advanced Open Labware Workshop* was to assist researchers to develop capabilities and local expertise to accelerate research and development in Africa. The workshop was a collaboration between TReND (Teaching and Research in Natural Sciences for Development in Africa) and the Universities of Cape Town (South Africa), Tuebingen (Germany), Sussex (United Kingdom) and Oxford (United Kingdom), as well as the Council for Scientific and Industrial Research (CSIR, South Africa) and funded by the Volkswagen Foundation. Initial teaching of open source principles has been carried out in previous TReND workshops to provide a foundation of open hardware and software development [3]. Stemming from this, an advanced workshop was organized to allow for teams to utilize the foundational skills developed to build innovative solutions for challenges faced in their own laboratories or research environments. Important aspects addressed by the workshop included:

1. Providing access to equipment: 3D printers, laser cutters, as well as hardware and software components that are otherwise not available, accessible or affordable to the participants.
2. Application of foundational knowledge of programming and circuit design (e.g. from previous workshops/courses) to implement solutions for unique challenges that the individual teams face in their research areas and institutes.
3. Interaction and collaboration from teams across the world and leveraging of expertise from across the groups.
4. Providing a platform on which to develop open labware solutions that can be shared and utilized across campuses and countries to solve problems; this can also be adapted to solve other problems as a result of the generic approaches followed.

Assessment of the course success was carried out through surveys, as well as informal interactions and feedback sessions. The aim was for participants to develop complete open scientific hardware, as well as be encouraged to document their efforts and deposit all project content in public repositories such as GitHub.

2. METHODS

The workshop was held in Muizenberg, Cape Town, South Africa in April 2018, with a number of facilitators and 24 participants developing the open labware projects: 8 teams with 3 participants per team from Nigeria, Ghana, Malawi, Cameroon, South Africa and Germany. Teams were required to submit proposals for their projects, and successful candidates were asked to formulate and submit a bill of materials required for the project. The various components were procured prior to the workshop and distributed on the first day to the teams to streamline the progress of the projects.

The course took place over 2 weeks (6 days per week) from the 16th of April until the 28th of April. The daily schedule was structured with a morning presentation or lecture session at 09h00 and then building sessions for the remainder of the morning. Building continued in the afternoons after lunch, and the days were typically wrapped up with an hour long dedicated documentation session for groups to be able to capture the progress made and challenges faced, ultimately to feed back into the open labware space for others to utilize and build on to their work.

As an introduction to the workshop, each team gave a presentation. The teams discussed the equipment they wanted to make, and highlighted their existing skill sets and the skills they hoped to acquire. Many of the teams had overlaps in terms of the types of equipment they wanted to create, which indicated a high possibility of good inter-team collaboration. There were also overlaps in skill gaps - such as PCB design and GitHub, which suggested useful content for tutorials to be presented as part of the workshop.

A 3D printer (Zortrax M200) was utilized during the workshop to assist in development of a number of the projects (Figure 1a). Numerous lectures and tutorials were given throughout the workshop (Figure 1b), with focus on open source hardware and software development and 3D printing design and manufacture.

Figure 1: a) 3D printing of various components during the workshop and b) one of several tutorial sessions on hardware and software development aspects provided as part of the workshop.

Additionally presentations were given by some of the facilitators to highlight their research and areas of expertise and interest. Presentations included:

1. Open source and open design – including examples of open hardware projects and companies started up on global scale. Gathering for Open Science Hardware (GOSH) community forums and upcoming events were also highlighted, along with open source toolkits, for example https://channels.plos.org/open-source-toolkit.
2. GitHub – installation, set-up and general functionality and implementation for documentation, collating and sharing of work. Hands-on interactive sessions were also carried out to ensure that all teams could utilize GitHub effectively for their projects.
3. Open 3D printing design programs – covering various programs with brief overviews of the functionality of each program. Pros and cons of each program for developing designs were presented according to user skills and preferences.
4. Documentation – the importance of keeping up to date documentation on the work being done and suggestions as to how to most efficiently do this.

Emphasis was placed on important design considerations for those who were inexperienced in 3D printing design, including the use of a bottom support base, support structures when creating bridges, and avoiding thin, tall structures. Different programs covered included OpenSCAD, Google SketchUp, FreeCAD and Tinkercad, to allow participants to design the customized parts required for their projects. Programs such as OpenSCAD employ a coding/programming approach with variables to determine dimensions and achieve different shapes from standard objects. With FreeCAD, different surfaces or edges are selected and operations are applied to the selected part. Google SketchUp and Tinkercad employ a drag and drop approach for creating and combining shapes.

Key points of the teaching methods of the workshop included a) planning to publish from the build experience and b) planning for open source documentation. There was also discussion about ensuring the maximal usage of the shared expertise by having break-away groups with members for different teams to discuss challenges as part of the daily schedule. Documentation of project work and progress was carried out by teams for the last session of each day of the workshop.

Three different surveys were compiled to assess 1) why the participants applied to the workshop, 2) the skills and knowledge learned, and 3) the implementation of the open labware developed as part of the workshop back at the home institutions – i.e. the future goal and implementation plan.

3. RESULTS

The various projects incorporated 3D design and printing, laser cutting and various electronic components. Arduino UNO and Raspberry Pi boards were utilized as processing, control and interface platforms. Tinkercad was a popular 3D design program choice for many of the teams as it employs a drag and drop approach for ease of adding and combining shapes. Many teams had no previous experience with 3D printing design programs or laser cutting and design processes. Some of the teams had experience with Arduino platforms, and where expertise was lacking, online forums were utilized. Interaction between teams was also commonly exploited where expertise was lacking and other teams had experience and insights to give.

The projects that formed part of the workshop included:

- **Analytical shaker project** (Ghana): Motor control system to shake 3D printed layers of sieves for particle sorting, specifically for pharmacology applications. 3D printed brackets were also made to cradle the motors for correct vibrations and motion to be achieved for the shaking of particles in a sample (Figure 2a).
- **Bird assessment project** (South Africa): Bird perch and nest modified from PrintedNest Project (http://www.printednest.com/) with the addition of a camera and load cell system to visually assess and weigh birds. The bird nest was 3D printed (Figure 2b), along with a number of other housing and structural components.
- **Spectrophotometer project** (Cameroon): Development of a precision wide spectrum spectrophotometer for various research applications within the laboratory (Figure 2c). Housings and brackets for positioning light sources and detector arrays were 3D printed.
- **Locomotor activity testing project** (Ghana): Infrared transmitter and receiver arrays in a box to detect rodent activity and speeds within the set-up (Figure 2d).
- **Multipurpose chamber for image and activity capture project** (Nigeria): chamber for activity capture of animal via camera imaging with constant lighting and ultrasonic sensors for passing through a doorway inside the setup. 3D printed brackets and housings were used for the camera setups.
- **Micropipette puller and Electroantennogram (EAG) project** (Malawi and Nigeria): development of automated micropipette puller and EAG system for insect olfactory research. A micropipette puller is required to produce glass electrodes for probing of the insect antenna and was implemented using heating elements.
- **Fluorometer project** (Germany) – fluorescence detection of DNA samples using specialized dyes. This project was fairly advanced, and the team's experience with spectrophotometry was utilized by other teams to accelerate their project development during the workshop.
- **Bee hive monitoring project** (Germany) – implementation of various sensors for bee hive monitoring and environmental parameters, with long-range wireless communication of data collected. This project was in the advanced stages, so the team could assist others with rapid development and troubleshooting where they had already overcome challenges.

The two projects from Germany were further advanced than the other projects, with optimization and improvements being the main goal for these teams during the workshop. The idea was to encourage cross-collaboration between the groups that were further along with implementation than those just starting with the development, with the more advanced groups giving insights into potential hurdles and how they overcame these to speed up development in the early phases for the other teams.

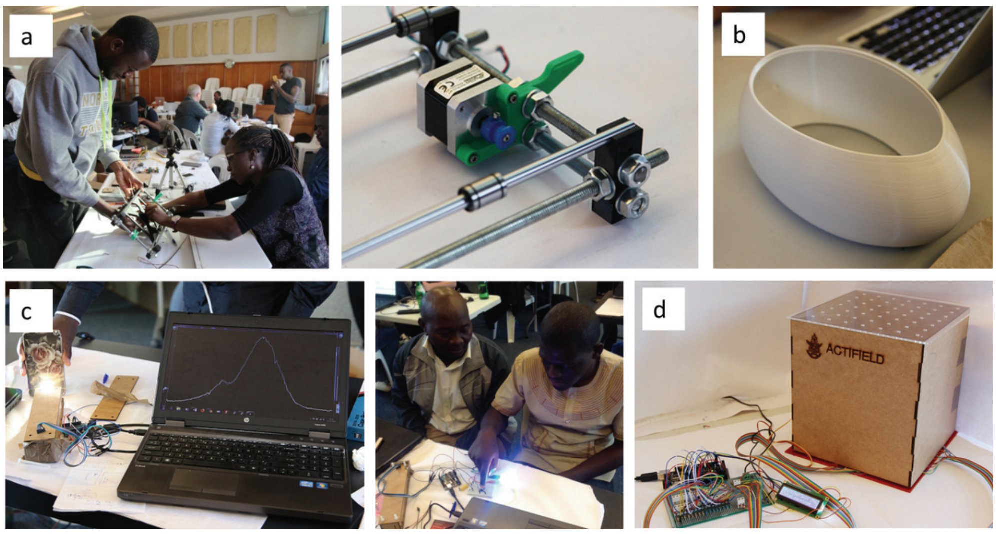

Figure 2: Development of 3D printed solutions during the workshop, including projects such as a) an analytical shaker, b) a smart bird nest, c) laboratory spectrophotometer, and d) locomotion activity test set-up. Image credit: Agnieszka Pokrywka (https://flic.kr/s/aHsmgp89ze).

There were challenges with regards to components not arriving on time that were addressed using local distributors,but impacted on the initial progress made during the first week of the workshop. This should be considered for potential future workshops, particularly when held in locations where local distributors may not be a feasible option.

With many of the teams needing access to a 3D printer, securing one for use in the venue had to be prioritized and proved challenging in terms of setup. In future, arrangements to make this a smooth process during the workshops should be planned before the workshop commences.

Surveys were conducted during the course of the workshop to assess the workshop expectations and success. Survey 1 was carried out in the beginning stages of the workshop and assessed the participants' background and reasons for wanting to participate in the workshop (Table 1). In all cases, participants applied to the workshop with the aim of learning how to use and implement tools to further or assist in their research careers. In cases where participants had previously worked on open labware projects, this was typically during previous TReND workshops, or in a few cases, during hackathons. Preparation time for the workshop typically ranged from a few days to 4 or 5 months across the teams, and in many cases, online or email discussions were the only options prior to team members meeting up at the workshop.

Survey 2 was carried out halfway through the workshop and assessed the skills and knowledge learned as well as areas where skills were lacking and that could potentially be improved on for future workshops (Table 2).

Survey 3 was carried out towards the end of the workshop and assessed the future goals and implementation plans for the projects after the workshop (Table 3).

Table 1. Workshop Survey 1 results summary to assess background and experience of participants. 21 responses were recorded.

Survey question	Yes	No
Before the workshop, had you ever heard of the open source philosophy?	19 (90.5%)	2 (9.5%)
Was this workshop your first project involving open labware?	13 (61.9%)	8 (38.1%)

Table 2. Workshop Survey 2 results summary to assess the learning process. Number of responses recorded varied as participants opted not to answer all questions.

Survey question	Responses given	Number of responses
What are you enjoying the most about the workshop?	1. Collaborations within and across teams 2. Learning new skills 3. Tutorial sessions 4. Interdisciplinarity	13 (68.4%) 4 (21%) 1 (5.3%) 1 (5.3%)
What are you finding the most challenging about the workshop?	1. Lack of skills in programming, hardware and troubleshooting 2. Restrictions in terms of time, equipment and space 3. Access to components	3 (37.5%) 3 (37.5%) 2 (25%)
What key skills have you gained during the workshop?	1. 3D printing design and programs 2. GitHub 3. Electronics 4. Programming 5. Documentation 6. Communication skills 7. Problem solving	6 (18.2%) 6 (18.2%) 5 (15.2%) 5 (15.2%) 4 (12.1%) 4 (12.1%) 3 (9%)
Are there additional types of skills you would like to acquire?	1. Programming 2. Electronics 3. Writing of scientific papers 4. GitHub advanced usage 5. Hardware design 6. 3D printing expertise	4 (26.7%) 3 (20%) 3 (20%) 2 (13.3%) 2 (13.3%) 1 (6.7%)

Table 3. Workshop Survey 3 results summary to assess future implementation of projects resulting from the workshop. Number of responses recorded varied as participants opted not to answer all questions.

Survey question	Average ranking (standard deviation)
When you take your equipment home, what will be the biggest challenge for you? Rank 1 to 5, with 1 being the biggest challenge. 1. Getting funds to maintain and upgrade your equipment 2. Getting parts to maintain your equipment 3. Issues of power and connectivity 4. Getting reagents/consumables for your equipment 5. Integrating your equipment into your existing laboratory environment	 2.4 (1.7) 2.7 (1.2) 2.9 (1.6) 3.4 (1.1) 3.8 (1.3)
Do you think there would be aspects of open labware that would discourage your colleagues from taking up this option? Rank 1 to 8, with 1 being the highest. 1. Lack of funds to buy hardware 2. Lack of access to tools for building (i.e. 3D printers) 3. Lack of expertise (or perceived lack of expertise) 4. The time it takes to build the equipment 5. Concerns about publishing data made on open labware 6. Lack of on-site technical support 7. Problems of calibration and data verification 8. Lack of institutional support	 3.3 (2.4) 4.0 (2.5) 4.1 (2.3) 4.1 (2.5) 4.7 (2.2) 4.8 (2.0) 4.8 (2.6) 5.3 (2.1)

4. DISCUSSION

Survey 1 (Table 1) showed that more than 90 % of the participants had heard of Open Source, but not necessary Open Hardware. More than 60 % of the participants had never engaged in an Open Hardware project before. Those who had, had done so through various sources, primarily workshops.

Survey 2 (Table 2) highlighted that the main contributor to the enjoyment of participants during the workshop was learning from others and collaborations. The biggest challenges faced varied across participants, and included lack of skills along with restrictions in time, equipment and components. Participants felt that various skills were gained during the workshop, particularly in 3D printing and sharing work on open platforms, but also that skills could be further developed, especially in software programming, electronics, and documentation.

Survey 3 (Table 3) summarized the biggest challenges faced by participants, along with the aspects of open hardware that could discourage their colleagues from taking this approach, with rankings from highest to lowest.

Although the answers varied regarding the biggest challenges, funding remained the largest concern for maintaining and upgrading of equipment once taken back home. Participants also highlighted the lack of access to tools for building (e.g. 3D printers, laser cutters, etc.) as development hurdles in the adoption of open labware at their home institutions, although answers again varied in terms of rankings.

5. CONCLUSION

The workshop assisted participants in resource-limited settings across Africa, as well as the rest of the world, to develop the skills to realize functional solutions for challenges in their laboratories and areas of research. Although the participants generally did not have backgrounds in electronics or programming they were able to learn basic design and implementation skills towards realizing practical solutions and to contribute to open labware developments, particularly through utilization of 3D printing techniques. Most teams were able to successfully complete the required project work during the two week period. The aim was for the teams to be able to take their developed projects back to their home institutions for use in laboratories and research projects and be able to teach others in their communities about open labware design processes and principles. Challenges regarding available funding and support mechanisms at the home institutions of the participants were highlighted, and future endeavours could include follow ups to track this progress.

ACKNOWLEDGEMENTS

Special thanks are extended to Samyra Cury Salek and the other members of the workshop organizational team for all their efforts in making the workshop a success, Thomas Euler for providing funding for Andre Maia Chagas as well as Volkswagen Stiftung for funding the workshop (grant number 92065).

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