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Kepler Tech Lab: Developing an affordable skills-based engineering lab course in Rwanda

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Kepler Tech Lab: Developing an affordable skills-based engineering lab course in Rwanda

Practical hands-on education remains one of the main challenges of science and engineering education worldwide [1]. Numerous innovations have made it easier for teachers to incorporate hands-on lab activities into their curricula, including commercially available student lab kits, virtual labs [2], and maker space technology [3]. However, these innovations are often expensive and inaccessible in lower-income communities.

In addition to adapting existing technologies from developed to developing contexts, we need to find novel approaches to incorporate hands-on activities into global engineering education. The following problems should be addressed at all levels of education:

1. Current engineering curricula are designed to teach concepts important for western concepts.
2. Lab equipment is expensive and requires outside training to repair.
3. High student-to-teacher ratios lead to only a small number of students learning well.

Recent work in this area includes: Practical Education Network (PEN) [4], which runs teacher training workshops on incorporating low-cost science lab experiments into secondary school classrooms in Ghana. Peace Corps volunteers in Tanzania have created Shika na Mikono [5], a practical guide with hundreds of low-cost experiments for constructing physics, chemistry, and biology laboratories in secondary schools. Seeding Labs [6] and TReND [7] provide refurbished lab equipment to research universities in developing countries as well as run an in-person training program for technicians using the equipment.

While most engineering education innovation in developing communities address the primary, introductory secondary and advanced university levels, there are few efforts focused on the advanced secondary and introductory university levels, where engineering students are at a critical point for developing essential career skills.

Purpose

We developed and implemented open-source curricula for enrichment programs at the advanced secondary school and introductory university levels in Rwanda. Our purpose can be broken up into three parts:

1. Identify important engineering topics that are relevant in the local community and build a curriculum around these topics to teach essential skills.
2. Identify availability and cost of lab equipment, and design a rigorous curriculum that primarily uses affordable and easily accessible equipment or equipment that can be easily built (<$5000 in materials costs).
3. Develop lab guides and other learning resources that allow students to work self-guided, with the teacher being a facilitator rather than a lecturer.

In this paper, we describe the methods used in developing the lab model, including curriculum design, equipment acquisition, assessment techniques, and teacher support. We also present results of sample student works and student feedback as a qualitative measure of the impact of the lab model. Finally, we present challenges and limitations of the model as well as further changes to adapt the model to other contexts.

Local partner organization

The project is a joint collaboration with students and staff at Kepler, in Kigali, Rwanda. Kepler is a private university program that uses a blended learning model to allow students to a get an American-accredited Bachelors of Arts (B.A.) degree from Rwanda. Students receive a B.A. in communications, health care management, or management. The Kepler administrative staff expressed interest in developing a low-cost science and engineering lab on their Rwandan campus as well as in training student leaders to manage the lab.

Students enrolled in the Kepler B.A. program played main roles in the design, teaching, and revision of the lab model. While Kepler teachers were not directly involved in designing and testing of the project, Kepler teachers provided teaching professional development to lab teaching fellows. The project is currently being headed by Alphonse Habyarimana, a current Kepler student, in Kigali, Rwanda. While this project is ongoing, the focus of the contents of this paper will be on work done from August 2015 to July 2016.

Methods

Curriculum design

We used an iterative process to design and test the engineering enrichment program curriculum. We considered three related factors: module topics, available lab equipment, and skills learned. The modified curriculum presented here follows from the results of: a 1-month initial field visit, 6 months of experiments testing in the U.S., and 4 months of curriculum testing with Kepler students in Rwanda.

The purpose of the modular curriculum was to expose the students to select broad engineering challenges that are highlighted in the Rwandan government's Vision 2020 document [8]. The specific experiment topics were then narrowed down based on student interest and cost of experimental materials. Each module was 4 weeks long with 9 hours of instruction each week, totaling 4 modules and 16 weeks for each class. The following modules were taught:

1. Engineering skills: students will be able to estimate uncertainties from raw data, program basic code in Python, use Python to draw quantitative conclusions from data, and visually represent data. Students will be able to make a short oral presentation on a technical topic.
2. Electronics recycling: students will be able to make and measure basic electronics circuits to make an amplitude modulated radio receiver.
3. Solar energy: students will be able to make and analyze basic (inefficient) solar cells.
4. Independent project: students will be able to brainstorm, identify, and research a technical problem in their community, and iteratively prototype and test a solution.

Daily pre-class activities included: reading the lab guide, answering questions about content of readings, or online simulations to review theoretical knowledge needed for experiments. Daily in-class activities included: doing experiments, answering questions from teaching staff, and data analysis. The pre-class and in-class activity materials were developed by teaching fellows, A. Habyarimana, J. Dahl, and Q. Yu by synthesizing multiple online materials. At the end of each module, students delivered a 15-minute public oral technical presentation with the following components: motivation, data collection methods, data analysis, and results.

Equipment acquisition

We constrained possible experimental topics to those that used materials readily available in Rwandan shops, could be ordered online with <1 month delivery time, or equipment that was easily built. While in the initial designs of the lab model we hoped to entirely use locally-available materials, we found that some local materials were low-quality and 2-5 times more expensive than materials that could be ordered online. Thus, we chose to order some electronic and machine shop materials online at Aliexpress.com. The lab materials totaled $3500, excluding infrastructure costs. A complete list of materials and their sources are available at keplertechlab.wordpress.com/technical/lab-equipment.

Assessment techniques: formative assessments

In response to feedback from local employers that university graduates had few practical skills, and in-line with Kepler's assessment method, we developed a set of 15 competencies for student formative assessment (see Table 1). The competencies were chosen based on prospective employers' feedback, ease of evaluation, and student interest.

Table 1: Competencies for student formative assessment
*Kepler general competency

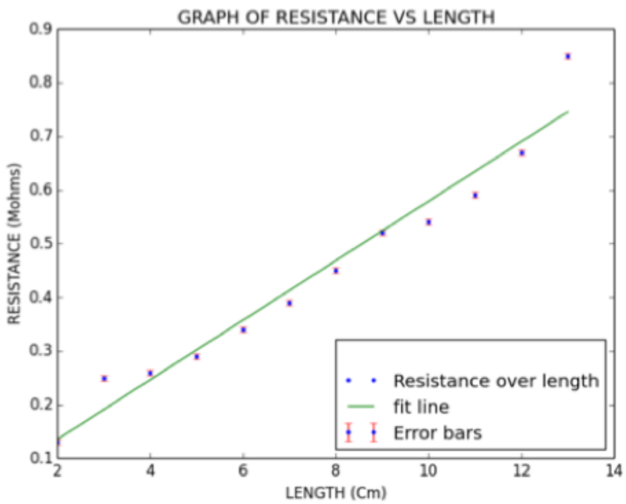
Lab Technical	Communication	Professional
Technical problem solving	Data analysis and visualization	*Takes initiative
Questions results	Documentation	*Works collaboratively
Systematic scientific thinking	Technical communication	Resourcefulness
Experimental setup		*Meets deadlines
Experimental design		
Safety management		
Building circuits		
Programming		

Students were assessed on a scale of 1-Novice, 2-Emerging, 3-Developing, 4-Proficient, 5-Advanced, to 6-Expert for each competency 1-4 times throughout the 16-week course and received both written and oral feedback after each assessment. All teachers and teaching assistants assessed students and the final score was averaged. Lab technical competencies were evaluated in specific modules by teacher observation, with the exception of programming, which was evaluated using student code. Communication competencies were evaluated during the 15-minute student presentation at the end of each module. Professional competencies were evaluated throughout the course at randomly chosen times by teacher observation, with the exception of the meets deadlines competency, where half-points were deducted from 6 (expert) for each late assignment.

Figure 2 gives an example of a competency rubric and a corresponding assessment of a sample student work by teachers.

Figure 2: Abridged competency rubric for "data analysis and visualization" competency and corresponding feedback of a sample student work by teachers.

This student work example satisfied the 3-Developing criteria because he/she plotted the data in an understandable way and chose a linear fit function. However, the student did not receive 4-Proficient because he/she did not discuss the meaning of the fit in the presentation.



Data analysis and visualization
4-Proficient: Can perform simple manipulations on datasets to extract secondary information. Can plot and fit data to simple polynomial and exponential curves in a way that makes the outcome of an experiment more understandable.
3-Developing: Can perform simple manipulations on datasets to extract some secondary information. Can plot and fit data to simple linear curves in a way that makes outcomes of an experiment more understandable.
2-Emerging: Can perform simple quantitative analysis on raw data and plot it in a form which aids in understanding the result.
1-Novice: Can qualitatively analyze simple results based on raw data.

Assessment techniques: summative assessments

In order to measure student success independently of the results of the formative assessments, we had students do an independently motivated project to demonstrate the skills they learned in the course. Project deliverables included a project proposal, 3 blog posts, and a 15-minute public oral presentation. Students were evaluated on the following four criteria due to their importance in global development engineering programs:

1. Innovation: Has the project idea been implemented before in this context? Did the student consider working with existing teams or brainstorm new ideas for the project?
2. Feasibility and affordability: Is it possible to develop/research something novel in the four-week independent projects period? If applicable, is it possible for the intended audience to afford the product?
3. Relevance to the community: Does the solution or research relate to important problems for the community? How likely is it for the intended user to use the technology?
4. Relevance to skills learned in class: How much does the project use skills that students learned in the class versus knew before taking the class?

For innovation, teachers guided students in brainstorming and doing background research on the internet and in the field. Each class did a 3-hour brainstorming exercise where the teacher gave 3-4 broad topic ideas (ex. agriculture, transportation, sanitation, etc.); students did internet research for 15 minutes on each topic; the whole class listed as many ideas as possible; students identified top choices for the above 4 criteria.

For feasibility and affordability, students were required to prototype any models from easily modified materials such as cardboard and paper before using more permanent materials such as wood and plastic. To address relevance to the community, students were given a small stipend to do field visits. For example, after visiting a nearby rice field and interviewing farmers about the current challenges they face, one student team became interested in creating a device to scare birds and other pests from fields.

Teacher support

We developed, tested, and revised open-source lesson plans and teacher troubleshooting guides, and the most current versions are available online at keplertechlab.wordpress.com/course-material. Each lesson plan contains learning objectives, competencies to be evaluated for that day, student pre-reading, a warm-up activity, in-class activities, experimental set-up, and common student questions and their associated answers.

In order to create a self-sustaining lab team, we also developed a teaching fellow training program to train new teachers. Teaching fellows were selected from Kepler student applicants and the criteria for selection included: basic science, engineering, or programming background; enthusiasm for educational innovation; ability to work in a team; leadership ability. Table 2 details the phases of the teaching fellow training program

Table 2: Phases of the teaching fellow training program

	2 weeks training	**16 weeks teaching assistant**	**Lead teacher**
Responsibilities	Learn basic technical skills, become familiar with lab goals	Review daily lesson plans with main teacher, facilitate small hands-on activities, evaluate students competencies, participate in weekly 1 hour professional development session	Lead a team of 1-2 teaching assistants, modify daily lesson plans based on pace of course and student interest, meet with lab manager on a bi-weekly basis to set and advance professional goals, participate in weekly 1 hour professional development session

Results

The results presented here are of two instantiations of the course from January – May 2016 (course 1) and April – July 2016 (course 2). The lead teacher in course 2 was a teaching assistant in course 1. Students were selected from a pool of local student applicants in 12th grade of secondary school and 1st year of university. Students were selected based on: (1) strong theoretical background, (2) little prior hands-on lab experience, (3) interest in a hands-on engineering or engineering management career, and (4) English proficiency. Course 1 had 39 applicants and course 2 had 70 applicants; 24 students were chosen for each course. While students did not receive credit for the course, they did received a certificate of completion with a list of their proficient competencies at the end of the course. Unfortunately, as the incentives for taking the course were mainly self-driven, we had only a 50% retention rate in both courses. Most students who dropped the course stated that another commitment had come up had taken priority. The qualitative results presented in this section are from the students who completed the entire course.

Summative assessment of independent projects
Students collaborated in pairs to brainstorm and test a wide range of independent projects in topics of agriculture, recycling, transportation, and energy. Table 3 gives student projects and the associated summative assessment.

Table 3: Sample student independent projects and the summative assessment criteria met: innovation (I), feasibility and affordability (F), relevance to community (Comm), and relevance to skills learned in class (Cla).

Student projects	**Description**	**Summative assessment criteria met**
Bus system simulation	Python model for simulating bus and passenger movement	I, Comm, Cla
Plastic recycling	Process for making thin plastic fibers from recycled plastic pieces	I, Cla
Crop data analysis	Analysis of supply and nutrition of different crops in Rwanda	I, Comm, Cla
Bike-powered generator	Prototype bike-powered cell phone charger	F, Comm, Cla
Fixing broken electronics	Process for repairing radios in local home solar installation systems	F, Comm, Cla

Student feedback
Students responded to optional feedback surveys at the end of each module and at the end of the course, with about a 50% response rate. Especially in course 1, students noted that some pre-reading material was too difficult, as they presented concepts that were unfamiliar. As a result, we decided to give less pre-reading material and incorporate mini-lectures into class sessions for course 2. Students responded better to more in-class activities and fewer pre-class assignments.

At the end of the course, most students felt that they had learned something they wouldn't have otherwise learned in their high school science and engineering courses. Below are a few quotes from students:

"My experience from Kepler Tech Lab helped me to be able to think and understand more of the experiences and the physical use of what I learned in theory from the beginning of my studies."

"Before Kepler Tech Lab started, I thought that hands-on experience requires a person to be an expert in what he is going to do. However, a person [can] learn more throughout entire experiment. It requires taking initiative and [an] optimistic mindset. [Whether] you fail or succeed, all results in experiment help a person to learn new things."

"From Kepler Tech Lab I gain knowledge in working with others, making a study on something to participate in resolution of problems and making research for more study."

Challenges and limitations

Challenges with the current lab model include:

- It is not financially sustainable as a standalone lab
- Course is introductory and students need more in-depth follow-up courses to further develop critical thinking skills
- Incentive models for students for the enrichment course need to be further developed

The lab model described in this paper is the result of lessons learned from a first model and the model described in this paper has since evolved to a third iteration, both of which are not described in this paper (see Table 4).

In the third iteration of the course, the current lab manager Alphonse Habyarimana is pursuing his and current student interests in incorporating more workshops on makerspace techniques (using arduinos, programming in SCRATCH), creative capacity building, and social entrepreneurship into the curriculum.

Table 4: Iterations of the lab model

	Topic focus	**Student population**	**Incentive model**	**Lead teachers**	**Main lessons learned**
Model 1: Aug. 2015-Dec. 2015	Science	20 first year university students at Kepler	Kepler credit	2 American university graduates	Engineering more engaging than science, large student population outside of Kepler interested in the course
Model 1: Jan. 2015-July 2015	Engineering	15 first year university and twelfth grade high school	Certificates	3 advanced Kepler students who were teaching fellows in previous iteration	Large student interest in makerspace technology
Model 3: Sept. 2015-	Engineering and makerspace	Middle school and high school	Certificates	Kepler student A. Habyarimana	

Conclusions and Future Work

In collaboration with students at Kepler in Rwanda, we developed and tested a low-cost engineering teaching lab model and implemented it with 12^{th} grade and 1^{st} year university students in Rwanda. While the course contains novel curriculum that is specifically relevant for the Rwandan context, many topics are also relevant for East Africa and other developing communities around the world.

There are two possibilities to address the low student retention rate. The first is to keep the course as an enrichment course and incorporate more external incentives into future iterations of the course. Ideas that we have considered include: higher registration fees, opportunities to apply for internship upon completion of course. The second, more long-term, option is to incorporate the lab course into a high school or university science program. While this presents some logistical and administrative challenges, we see this as being the most financially sustainable option for this type of low-cost lab model.

We have done initial tests of the model in a refugee camp setting in rural Rwanda and have found that the model attracts interest from refugee students. In addition, we have implemented some of the hands-on activities described in the curriculum as a part of a one-day engineering outreach day for local high school and university students in Kigali, Rwanda and received enthusiasm from participants. Thus, we see that components of this course model can be applicable in situations where cost, teacher training, and strict curricula are challenges, including: schools unable to afford a laboratory, refugee camps, or afterschool enrichment programs.

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