HVK Final Report: Improving the Lab-in-a-Box user experience for students in Liberia

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HVK FINAL REPORT IMPROVING THE LAB-IN-A-BOX USER EXPERIENCE FOR STUDENTS IN LIBERIA

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ABSTRACT

To close gaps in access to STEAM (science, technology, engineering, arts, and math) education and student learning in Liberia, Hawah V. Kamara (HVK) Children's Foundation partnered with the Global Sustainable Aid Project (GSAP) organization to develop the Lab-in-a-Box system. The Lab-in-a-Box, an offline database, allows teachers and students in remote areas with limited Internet access to access teaching and learning materials. Our team partnered with HVK to improve the user experience for teachers and students, identify a new content management platform with login and monitoring systems, add new educational content, improve the bandwidth and battery of the system, and develop training programs to instruct onsite staff in setting up and operating the system.

ACKNOWLEDGEMENTS

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Besides our advisors, we would like to thank our sponsor, the HVK Children's Foundation's CEO and co-founder Jermoh Kamara, and Lab-in-a-Box personnel, Abdullah Sonnie, for giving us this wonderful opportunity to learn about and improve the Lab-in-a-Box, which will help generations of students in Liberia.

We also would like to thank all teachers and students in Liberia in participating in our surveys. We cannot express enough thanks to our classmates and professors for participating in our focus group study in evaluating the training programs.

EXECUTIVE SUMMARY

Introduction

To close the knowledge gap in children living in poor communities in Liberia and to increase access to technology and STEAM (science, technology, engineering, arts, and mathematics) education, the Hawah V. Kamara (HVK) Children's Foundation was founded as a nonprofit organization in 2016. The organization partnered with the Global Sustainable Aid Project (GSAP) organization to establish the Lab-in-a-Box system, which enables students and teachers to access resources offline. The offline status is necessary because only five percent of Liberians have Internet access, making Liberia one of the least connected countries in the world (USAID, 2018). Currently, HVK has implemented the system in three schools in rural areas of Monrovia, Liberia. By establishing the system's portal, which can be accessed by inexpensive tablets and computers in schools, educational resources can be accessed offline to enhance teaching quality and student performance. The Lab-in-a-Box has helped numerous Liberian students, and the system could be improved to maximize its efficiency and the satisfaction of users. Our project researched ways to increase the bandwidth to allow more devices to connect to the system simultaneously, create separate login pages for teachers and students, implement a monitoring system to keep track of user activity and learning progress, boost the battery capacity of the system, add updated content to the database, and reorganize these content in a different content management platform.

EXECUTIVE SUMMARY

Background

The United Nations International Children's Emergency Fund (UNICEF) approximated that 15 to 20 percent of children 6-14 years old are not in school in Liberia, which has one of the highest school dropout rates in the world (Ministry of Education in Republic of Liberia, 2016). According to the Ministry of Education in Liberia (2016), these dropout rates are primarily due to poverty, civil wars, and the 2014-15 Ebola outbreak. Government corruption has also resulted in poverty and limited education access. George Weah, the President of Liberia, has been accused of corruption due to the construction of luxury housing estates and costly renovations of his own residence (Lee-Jones et al., 2019). From surveys conducted by the World Bank on Liberian citizens, only 52% of people responded that they believe that the government is making a difference in the fight against corruption, six out of 10 individuals reported that they fear retaliation if they report corruption, and two-thirds of people stated that they believe that the authorities will do nothing even if they do report instances of corruption (Lee-Jones et al., 2019).

Another factor impacting education in Liberia is that not enough instructors are certified to teach. Only 50.6% of teachers have proper training and are certified to teach (Ministry of Education in Republic of Liberia, 2016).

The Ministry of Education (2016) also stated in the analysis that at least 700 certified teachers do not have high school diplomas. Without qualified teachers, the process of teaching and learning in schools is ineffective and could result in low student performance.

The United Nations Educational, Scientific and Cultural Organization's (UNESCO) Institute for Statistics estimated that more than 617 million children and adolescents of primary and lower secondary school age around the world do not achieve minimum proficiency levels in reading and mathematics (UIS, 2017). The World Bank (2018) stated that Sub-Saharan African countries have a lower median percentage of primary school students who score above a minimum proficiency threshold in reading and mathematics assessments. To address this problem, many offline educational platforms have been created such as World Possible's Remote Area Community Hotspot for Education and Learning (RACHEL), Learning Equality's Kolibri, Ustad Mobile, and E-learning for Kids to bring learning opportunities closer to students in poverty without Internet access (Kolibri, n.d.-a; UNESCO, 2020). Likewise, HVK's Lab-in-a-Box has made significant and meaningful contributions to teachers and students in Liberia.

EXECUTIVE SUMMARY

Methodology

Our goal was to improve the user experience of the Lab-in-a-Box portal. There are four objectives that we addressed:

1. Understanding the Lab-in-a-Box portal and the current curriculum in Liberia.
2. Improving the wireless connection and battery capacity.
3. Updating the portal with updated content and organizing them in a new content management platform with a login system and a monitoring system.
4. Developing training programs for teachers and staff on operating the portal.

To understand our objectives and the latest experience and concerns with the portal, we conducted interviews and surveys. We interviewed two people: the founder of HVK Children's Foundation and Lab-in-a-Box personnel in Liberia. The interviews allowed us to understand the scope of the project, the expectations of our sponsor, and the concerns with the system. We conducted surveys on teachers and students who use the system in Liberia, and their responses helped us to verify and quantify mentioned concerns, and to understand their preferences for new content. Based on the responses, we strategically planned ways to address each objective.

After understanding the Lab-in-a-Box system and curriculum in Liberia, we set up the Lab-in-a-Box we received from the sponsor and conducted experiments to check the connectivity (bandwidth) of the system and perform a power analysis.

Then, we conducted secondary research to find new content management options with separate login pages for students and teachers and a tracking system to monitor students' user activity. After finding potential offline content management options that could replace the GSAP portal currently used by the system, we presented our sponsor with a comparison table to reflect their pros and cons. With the sponsor's approval, we replaced the GSAP portal, which lacked login and monitoring systems, with Kolibri. All content on the Kolibri platform we adopted were directly added from the Kolibri database. We organized content by grade level groupings from Early Childhood to College after we had transferred new content based on requests received from interviews and surveys.

Lastly, we designed a tutorial video and an instruction manual pamphlet to train teachers and staff in setting up and operating the Lab-in-a-Box. To make effective training programs, we interviewed a WPI instructional media specialist with expertise in developing interactive learning materials. After creating the tutorial video and instructional manual pamphlet, we conducted a focus group study online through Zoom, in which participants evaluated the training programs through Qualtrics online surveys after watching the video and reading the pamphlet.

EXECUTIVE SUMMARY

Results & Analysis

From the interviews and surveys, we learned that the Lab-in-a-Box has major software and hardware issues. Software concerns refer to the need for and lack of up-to-date features and content, whereas hardware concerns have to do with suboptimal functioning of components of the system such as the router, battery, and solar power panel. We also created training platforms to instruct the staff on setting up and operating the Lab-in-a-Box properly.

For software issues, interviewees identified a need for separate login pages for students and teachers, a monitoring system to track user activity, and a more organized database for content management, which are features the current GSAP portal lacked. We identified alternatives to the GSAP portal such as Nicepage and Kolibri, presented our sponsor with a comparison table to show pros and cons of each option, and Kolibri was selected. Kolibri includes separate logins, a monitoring system, a quiz/assignment system, and creation of admin and user accounts. Kolibri also functions similar to the GSAP portal in terms of distributing content in an offline setting.

We learned about the content preferences of HVK representatives, teachers, and students. Interviewees identified the need for new content, especially history content on Africa and Liberia. Most teachers (approximately 65%) indicated that they taught science-related content the most, followed by English (20%) and math (15%). Students preferred the subjects (math, science, and English) roughly equally. Teachers (65%) informed us that they would like to see more video content for their materials. All the quantitative data from our surveys informed us to focus more on STEAM (science, technology, engineering, arts, and math) content accompanied with educational videos as we updated the portal with new content.

We discovered consistent hardware problems such as devices disconnecting frequently from the Lab-in-a-Box and the very limited battery capacity. For example, when asked about how often devices disconnected from the portal, 55% of teachers answered "Sometimes", and as many as 35% responded "About half the time." Likewise, 18 out of 20 teachers stated that connectivity between the devices and portal was the main problem, which was also highlighted by the interviewees. In addition, the Lab-in-a-Box personnel and two of 20 teachers stated that they would like the power to be improved.

EXECUTIVE SUMMARY

Results & Analysis

We found the specifications of the RavPower travel router, which was at the time used by the Lab-in-a-Box in Liberia. It had a 2.4 GHz frequency band, 802.11b/g/n wireless standards, and a data transfer rate (maximum bandwidth) of 300 Mbps. The personnel noted that in one classroom, at least five devices simultaneously connected to the travel router. Although it is a small number of devices, they would often get disconnected every 5 minutes. Based on our research regarding the disadvantages of the low WiFi frequency band, 802.11 b/g/n wireless standards, and data transfer rate of the RavPower travel router, we hypothesized that the frequent disconnection was caused by low bandwidth. From our bandwidth tests, in which we compared the RavPower travel router to a home router and Raspberry Pi 4, we found that the download speed of the travel router was almost 0 Mbps when 30 content (the equivalent of 30 devices) were run simultaneously. On the other hand, we found that the download speed of the TP-LINK AC1750 home router stayed stable at approximately 115 Mbps when 30 content were opened. Although we could not execute the bandwidth test on the Raspberry Pi 4 because the Kolibri operating system (OS) had a firewall, we still were able to run 30 content smoothly on one device using the Raspberry Pi 4. We also effortlessly connected seven devices to the Raspberry Pi 4 while running HD videos simultaneously.

For the power analysis of the Lab-in-a-Box, we found that the solar panel supplied ample power to the battery at a maximum power voltage of 18 Vpm with 5.56 amps. At full capacity, the solar panel could produce 100 watts for each hour it is in direct sunlight. Next, we learned that the battery voltage was 12 V and could produce 100 Ah, which translates to 1200 Wh (1.2 Kwh) of power. This would be ample power running just the Lab-in-a-Box system. We also found that the power inverter could produce 300 watts with an input of 11-15 V in DC and an output of 110-120 V in AC with 4.8 amps flowing through the inverter using 75.6 watts per hour.

The interviewees also wanted training programs on both the hardware and software aspects of the Lab-in-a-Box. The need for training materials was confirmed, as only 55% of teachers noted that they were extremely comfortable with operating the Lab-in-a-Box, while 35% found it neither comfortable nor uncomfortable. We created a tutorial video and pamphlet with steps demonstrating how to set up and operate the Lab-in-a-Box system.

EXECUTIVE SUMMARY

Recommendations

Based on the results, we recommend our sponsor replace the GSAP portal with Kolibri, invest in a Raspberry Pi 3 or 4 to implement Kolibri and a 512GB microSD card for storage expansion, conduct additional research to ascertain the actual cause of the power issues, and measure the physical dimensions of schools to estimate the amount of wire needed. We also recommend using the training programs we created to instruct the staff on how to properly set up and use the Lab-in-a-Box.

We recommend that HVK replace the GSAP portal used by the Lab-in-a-Box with Kolibri because it has all the features they want: separate login and monitoring systems and classroom, assignment, and quiz management systems.

The current RavPower router has connectivity issues due to its limitations and capabilities. To replace the GSAP portal with Kolibri, we suggest investing in a model 4 Raspberry Pi with 8GB of RAM, which also comes with a built-in WiFi and can connect to more than 10 devices simultaneously without a router. However, if the sponsor decides to keep the current setup, we recommend the TP-LINK AC1750 home router, as it would increase the connection capacity (bandwidth) of the Lab-in-a-Box from five devices to 20-30 devices. With the ability to run at 1750 Mbps and connect to 20-30 devices at once, this router presents the best value, download speeds, and will suit the needs of HVK.

At the time of our study, the Lab-in-a-Box used a 64GB flash drive to store content. To expand the portal with new content, bigger storage capacity was required because the current flash drive was almost full. We recommend investing in a 512GB microSD card, which is affordable and portable with more space for new content and future updates if they choose to implement the Kolibri-on-Raspberry Pi setup. If the sponsor chooses to keep the current GSAP portal setup, we recommend a 128GB flash drive instead, which is also affordable and portable.

From the overall power analysis, we were unable to determine the actual cause (or causes) of the power issues plaguing the Lab-in-a-Box system. We recommend that additional research be conducted to identify and address the cause (or causes) of the power issues, whose resolution would promote more learning by allowing students more usage time on the system.

To save money for HVK, we recommend the teachers and onsite personnel get measurements for each school before they install solar panels. To get the measurements, they should find a location within the classroom that is protected from the rain and use a tape measure to find the distance between each power component of the Lab-in-a-Box.

Since we learned that even some of the current staff are not confident with setting up the system, we recommend our sponsor utilize the visual and detailed tutorial video and manual pamphlet we created to train staff to be more confident in setting up and operating the Lab-in-a-Box.

EXECUTIVE SUMMARY

Conclusion

The HVK Children’s Foundation strongly believes that education is an invaluable key to a better tomorrow and created the Lab-in-a-Box to provide access to high-quality education for young students in impoverished, electricity-deficient rural areas of Liberia. We envision that the ideal Lab-in-a-Box system should run smoothly for years to come. Updating both the software and hardware components of the system will resolve its outdated-technology limitations and allow more space and capabilities for the Lab-in-a-Box in the future. Our research shows the ideal Lab-in-a-Box will run Kolibri software on a Raspberry Pi connected to a high-storage capacity device (microSD card or flash drive) that will provide sufficient space to store more information and facilitate regular updates. Our training programs will help teachers and staff onsite properly set up and operate the system. This project helped us appreciate more the technology and education opportunities we have by reminding us that we sometimes take for granted the almost unlimited access to technology and education we have in developed countries.

AUTHORSHIP

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1 INTRODUCTION

"One child, one teacher, one book, and one pen can change the world" is a famous quote by Malala Yousafzai, the Nobel Prize laureate and Pakistani activist who has been a tireless campaigner for the education of women and children in Pakistan and the rest of the world (Dickson, 2015). Education is a ticket that offers people a chance to change their destinies. That is the belief of many children and families in developing and underdeveloped countries. However, not everyone has the privilege to access education. In 2017, the United Nations Educational, Scientific and Cultural Organization's (UNESCO) Institute for Statistics estimated that more than 617 million children and adolescents of primary and lower secondary school age do not achieve minimum proficiency levels in reading and mathematics (UIS, 2017). In 2019, it was estimated that 128 million primary and secondary school children are out-of-school in crisis-affected countries (Plan International, 2019). In Liberia, which has one of the highest school dropout rates in the world, it was estimated by the United Nations International Children's Emergency Fund (UNICEF) that 15 to 20 percent of children aged 6-14 are not in school (Ministry of Education in Republic of Liberia, 2016). According to the Ministry of Education in Liberia (2016), these dropout rates are mainly due to poverty, civil wars, and the 2014-15 Ebola outbreak. Even though Liberia has experienced many major historical events, which have impacted thousands of lives, it has been making some gradual progress towards improving its educational system.

To help Liberia start a new chapter, the non-profit Hawah V. Kamara (HVK) Children's Foundation was founded in 2016, which then partnered with another organization called Global Sustainable Aid Project (GSAP) that was founded by faculty at Providence College. The GSAP developed the Lab-in-a-Box system, which HVK implemented in three different schools in Liberia. This is an offline web-based system that serves up to 25 devices (tablets, computers, etc.) and allows students and teachers who do not have Internet access to access its offline website database called the Lab-in-a-Box portal or GSAP portal, which has a variety of STEAM (science, technology, engineering, arts, and math) and history resources at both the primary and secondary levels. The system being offline is important because only approximately five percent of Liberians have Internet access, making Liberia one of the least connected countries in the world (USAID, 2018).

Many organizations have helped provide access to education for students without Internet access in developing nations. Organizations like UNICEF, USAID, OSIWA, and others have donated millions of dollars to improve Liberian education after the civil wars that crippled the education system (Gbollie & Keamu, 2017). Non-profit organizations such as World Possible and Learning Equality have created free offline educational platforms such as RACHEL and Kolibri to bring learning opportunities closer to impoverished students (Kolibri, n.d.-a; UNESCO, 2020). Likewise, HVK's Lab-in-a-Box has helped to close knowledge gaps among students in Liberia, and we worked with HVK to improve the effectiveness of the Lab-in-a-Box.

The goal of our project was to improve the quality of education by updating the Lab-in-a-Box system in various ways. A new design would provide students and teachers an optimized user-friendly experience. We established four objectives to achieve by the end of the study. Objective 1 was to understand how the Lab-in-a-Box works and the current curriculum in Liberia. In Objective 2, we examined the power source and state of the wireless connection to maximize battery capacity and the number of devices connected to the system at the same time. For Objective 3, we updated the portal with new content. For Objective 4, we created training platforms to instruct teachers on how to set up and use the system. By streamlining the system, our project improved the quality of education for students in Liberia.

Next, Chapter 2 is the literature review we conducted during our research, discussing the causes and impacts of factors such as civil wars, the Ebola outbreak, government corruption, and educational technologies and programs on education in developing countries like Liberia. Chapter 3 entitled Methodology presents the strategies, rationale, and plans we used to achieve the project goal. Chapter 4, which is the Results chapter, presents the issues we found to have plagued the user experience, and what we learned about the connection between the Lab-in-a-Box and devices and the effectiveness of the training programs (a video tutorial and manual) we created on setting up and running the Lab-in-a-Box. Lastly, Chapter 5 concludes the report with our recommendations based on the findings for HVK to consider and plan for future changes, and Chapter 6 includes our concluding remarks.

2 LITERATURE REVIEW

To truly understand the challenges that inspired the founding of the HVK Children's Foundation, we researched the hardships and the underlying problems with education in Liberia. Limited access to education is also a global issue; thus, we will start by discussing problems on a global scale and then how these issues affect Liberia. We will discuss the causes and effects of limited access to education worldwide, the impacts of historical events and government corruption on the lives of Liberians, the Liberian education system, the school dropout rates in Liberia, existing educational programs and future plans by the Liberian government, and interactive-learning technologies that are similar to the Lab-in-a-Box.

2.1 Causes and Impacts of Limited Access to Education

According to the United Nations, education is a basic human right and should be free at least at the elementary level (UNESCO, 1948). However, not every child has the chance to attend school. According to UNESCO Institute for Statistics (UIS) (2016), it was estimated that 263 million children were out of school in 2016. This huge number indicates there is still a lot of work to be done to increase education access around the world.

There are many social factors preventing children from attending school and developing the knowledge they need to start a new chapter in their lives. One of the top reasons is poverty. For many families, not enrolling children in school allows them to save money to buy food, water, and necessities, which are far more important for survival. This is supported by Maslow's hierarchy of needs, shown in Figure 1 below, which states that poverty forces people to prioritize physiological needs above higher needs such as love and belonging or esteem (Pichere, 2015). In 2020, the Global Campaign for Peace Education (2020) estimated there were approximately 386 million children living in extreme poverty. According to The World Bank (2018), children from low-income families performed poorly in mathematics and reading: only 13.9% could do mathematics, while only 4.5% could read. Many low-income families cannot afford consumer technology and the Internet. Approximately 50% of students globally do not have access to computers, and 43% do not have access to the Internet. Because of poverty, the impoverished students cannot afford the tuition and technology to accommodate their study, so their performance falls behind that of their peers from higher-income families.

Figure 1. The five levels of Maslow's hierarchy of needs (McLeod, 2020)

The COVID-19 pandemic has exacerbated disparities in education access. Before the COVID-19 crisis, limited access to education was already significant. As of 2020, there were at least 258 million out-of-school children and adolescents of primary and secondary school age globally (Global Campaign for Peace Education, 2020). The pandemic has negatively impacted poorer countries more than developed countries such as the United States and European countries. Developed nations have been able to mobilize advanced technologies and healthcare systems to battle the pandemic. In education, for example, students have been able to continue their studies online, and sometimes even in person. However, there are many countries without these advantages, and their schools have often had to close down completely. This has interrupted the learning process of more than 1.5 billion children across 188 countries (Global Campaign for Peace Education, 2020). In addition, 42 to 66 million children are at risk of falling into extreme poverty due to the pandemic (United Nations, 2020). As a result, the families of many of these children will be unlikely to send them back to classes even when schools reopen (United Nations, 2020). The impacts of the pandemic could last for years, especially as the number of cases show few signs of decreasing. Although some vaccines are becoming available, the buying power of the richer nations means that poorer nations are likely to be left at the back of the queue. Besides the COVID-19 pandemic, there are other causes of poverty in Liberia such as the civil war, Ebola epidemic, and government corruption.

2.2 Impacts of Civil War, Ebola, and Corruption

The Liberian education system is currently enduring a rebuilding phase following the brutal civil wars and massive Ebola outbreak. These crises devastated an already fragile education system. The 14 years of civil war (1989-1996 and 1999-2003) have decimated Liberia's education personnel, with great numbers fleeing the country or dying in the conflict. To increase the number of children in school, education for first to ninth grade is free by law and obligatory in Liberia (Gbollie & Keamu, 2017). Even with this requirement, the enrollment rate for primary school is only 44% (*Education | Liberia | U.S. Agency for International Development*, 2017). There are currently many organizations assisting with building schools and training more teachings; however, this is going slowly due to the lack of strong education infrastructure in the country. Furthermore, in 2014, there was an Ebola outbreak with the largest numbers of cases in West African countries, including Liberia, Guinea, and Sierra Leone. The epidemic ended in 2016 after more than 10,000 cases and 4,800 deaths in Liberia (BBC, 2016). Because of the Ebola epidemic, schools were closed for at least 6 months, and some had difficulty returning to school after schools reopened because Ebola was more common in extremely poor communities (BBC, 2016; PLOS, 2016). Civil wars and the Ebola outbreak have together killed thousands of people, broken many families and businesses, and pushed many children into extreme poverty and out of education.

Liberia has had many years of peace since the civil wars, but a new issue now plagues the country: corruption. The structure of the government of Liberia was inspired by the model of the government of the United States of America. The Liberian Constitution of 1847 established three separate branches: executive, legislative, and judicial. Political parties were accepted and legalized in 1984. A new constitution was introduced in 1986, which adopted a similar structure of government to the 1847 Constitution. Liberia is currently a multiparty republic, in which a president is elected to be the head of state and government and serves for six years (Jones et. al, 2020; Constitute Project, n.d.). The present government is the result of a peaceful transfer of power in 2017; however, it has been widely criticized for being corrupt at all levels. The independent corruption watchdog of Liberia, the General Auditing Commission, accused 20 ministers in Ellen Johnson Sirleaf's administration of corruption. However, none of the accusations were pursued and prosecuted with the reasoning given that the judiciary was "too weak." Sirleaf was President of Liberia from 2006 to 2018 and shares a 2011 Nobel Prize with two other people for promoting women's rights (The Editors of

Encyclopaedia Britannica, 2020). Nevertheless, it was found that in her second term in office over 20 of the biggest logging contracts in the country were awarded illegally. Despite this, once again no prosecution was pursued. These are just a couple of examples of the pervasive corruption in her administration.

George Weah was elected as president in 2018 with a mandate to take on corruption in Liberia, but his follow-through has been less than stellar. Weah himself has been accused of corruption following suspicious involvement in the construction of luxury housing estates and expensive renovations of his own home (Lee-Jones et al., 2019). The World Bank conducted an evaluation of corruption in Liberia and surveys with citizens of the country showed that corruption is a serious problem. Only 52% of people think that the government is making a difference in the fight against corruption (Lee-Jones et al., 2019). The issue is that six out of 10 people responded that they fear retaliation if they report corruption, and two thirds of people stated that they believe that the authorities will do nothing even if they do report instances of corruption (Lee-Jones et al., 2019).

The impacts of corruption severely limit the country's ability to focus on rebuilding important aspects of society. The corruption is so pervasive that it is difficult for the departments that require funding, like the Education Department, to receive it and not have it siphoned away into private pockets. Ultimately, corruption breeds distrust and discord in the government.

2.3 Liberian Education System

After the civil war, the Ministry of Education established a uniform Liberian educational system. This has four educational stages: pre-primary, primary, secondary, and tertiary. The journey from pre-primary school to graduation with a college degree takes approximately 20 years to complete. Children start to go to pre-primary schools at the age of two, and pre-primary education lasts for four years. This is followed by six years in primary schools. Junior high schools last for three years, and senior high schools consist of another three years. In order to study in college, students are required to pass the West African Examinations Council (WAEC) examination. Undergraduate college programs typically take four years to complete. The time needed to obtain master's and doctorate degrees is similar to that of the American system (two years for a master's degree and anywhere between three to seven years for a doctorate). Community colleges also exist in Liberia and require two years for completion (Ministry of Education in Republic of Liberia, 2010; Ministry of Education in Republic of Liberia, 2016).

In the Liberian education system, schools are categorized as either public or private, where the former usually refers to government schools and the latter non-government schools. Within government schools, there are public and community schools. Within non-government schools, there are private and faith-based schools. According to the Ministry of Education in the Republic of Liberia (2016), the majority of senior high school students attend private schools. Nevertheless, public schools still have the highest number of students across the board from Early Childhood Education (ECE) to senior high because they are more affordable than private schools (Ministry of Education in the Republic of Liberia, 2016). This indicates that many poor families depend on the government and government funding for school so that students can earn the same education as those who can afford to study at private schools.

Many teachers in Liberia are not qualified to teach. Only 50.6% of teachers (Table 1) have proper training and are certified to teach (Ministry of Education in Republic of Liberia, 2016). That shows that about half of teachers in Liberia are unqualified. The Ministry of Education also stated in the analysis that as of 2016 at least 700 teachers do not have high school diplomas (Ministry of Education in Republic of Liberia, 2016). Without qualified teachers, the process of teaching and learning in schools is ineffective and can potentially lead to poor performance among an alarming number of students. Figure 2 indicates that countries in Sub-Saharan Africa such as Liberia have a lower median percentage of primary school students who score above a minimum proficiency threshold in reading and mathematics assessments (The World Bank, 2018).

Table 1. *Number of qualified teachers*

Sector	ECE	Primary	Junior High	Senior High	Total
Qualified	7,048	18,975	4,295	2,219	32,537
Unqualified	7,263	11,247	8,688	4,230	31,628
Total	14,311	30,438	12,983	6,549	64,281
% qualified	49.2%	62.3%	33.1%	33.9%	50.6%

Note. From "Getting to Best Education Sector plan", by the Ministry of Education in the Republic of Liberia, 2016, p. 144, (https://www.globalpartnership.org/sites/default/files/getting_to_best_education_sector_plan_2017-2021._liberia.pdf)

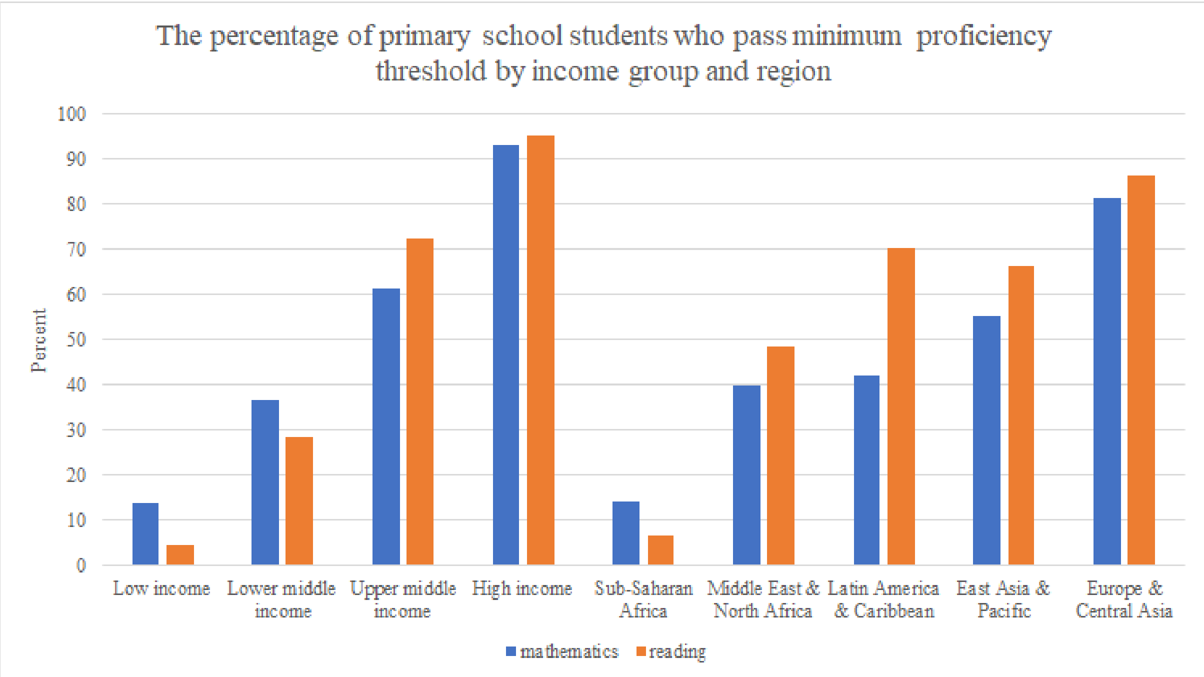

Figure 2. The percentage of primary school students who pass minimum proficiency threshold by income group and region (The World Bank, 2018)

2.4 Number of Students Not in School in Liberia

One problem that urgently needs to be addressed is the high number of school dropouts in Liberia. The country has witnessed many major historical events, and these have made it one of the poorest Sub-Saharan African countries and least developed countries in the world (UNICEF, 1996). According to Liberia's Education Ministry, the country has one of the highest rates of children not attending school: between 15 to 20% for children aged 6-14 (Ministry of Education in Republic of Liberia, 2016). According to Table 2, the number of student dropouts in 2015 was highest in the group of children aged 6-11, which means many young children and adolescents do not have basic yet important foundations that will eventually prepare them to pursue higher education later in life. The number of dropouts is predominant in rural and poor communities, where fewer than 28% of children attend school, compared to 50-60% of children from wealthier families. This means that children from lower-income families are less likely to develop crucial fundamental skills.

Table 2. *Number of students dropout in Liberia in 2015 by age-group*

	2015
Children aged 6-11 who are not in school	121,598
Children aged 12-14 who are not in school	52,028
Children aged 15-17 who are not in school	26,905

Note. From "Getting to Best Education Sector plan", by the Ministry of Education in the Republic of Liberia, 2016, p. 126, (https://www.globalpartnership.org/sites/default/files/getting_to_best_education_sector_plan_2017-2021._liberia.pdf)

There are many barriers to education that children living in poverty face. According to the Ministry of Education in the Republic of Liberia (2016), the four factors that determine the ability to attend school are school tuition and other expenses, poverty, late enrolment, and the distance between home and school. In 2016, the Ministry of Education created a survey to understand the main reasons for school dropouts. Table 3 shows the most common reasons for dropping out of school in poor households (Quintiles 1 and 2) and those in rural areas, which were poverty and expensive school tuition. The quintiles in Table 3 refer to the variety of degrees of poverty where Quintiles 1 represents the poorest groups and Quintile 5 represents the population with the highest income (Chen, 2020). This evidence further supports the link between poverty and limited access to education.

Table 3. *Reasons for dropping out of school*

Factors	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Urban**	**Rural**
Completed school	4.2	10.5	15.8	23.0	34.1	26.6	18.3
Lack of money/too expensive	50.4	45.7	41.8	40.0	31.4	41.0	36.7
Is working (home/job)	28.9	23.9	25.3	24.3	26.4	23.3	28.0
Got married	16.5	19.9	17.1	12.7	8.1	9.1	17.0

Note. From "Liberia Education Sector Analysis", by the Ministry of Education in the Republic of Liberia, 2016, p.71, (https://drive.google.com/file/d/0Bw00_oC-cHPvSHVZMHRHVkltNjg/view)

2.5 Existing Programs and Future Planning

The Liberian government has attempted to improve education through experimentation. In September 2016, it explored privatization as a possible means of improvement. Despite objections, the government formed the Partnership Schools for Liberia (PLS) program by handing 93 public schools over to eight private educational contractors (Laws, 2018). When the performance of students in the PLS schools was compared to that of students in non-PLS public schools (the control group) within a year of the experiment, the former had learning gains of 60% higher than the latter in subjects such as English and math (Laws, 2018). However, according to Laws (2018), the PLS students learned more effectively because their schools were already more privileged public schools prior to the experiment: they were better funded, had more teaching hours and fewer numbers of students per class, and had better-trained teachers than the control schools. Despite the high costs of the PLS program and its requirement for small classes and low enrolment, the government has continued to increase funding, increase the student-to-teacher ratio, include a meal plan, and expand the program to other regions of the country, including the most disadvantaged regions such as the Southeast of the country (Romero et al., 2017). Nevertheless, Romero and others (2017) note that even in these areas the program will select the more advantaged public schools. The experiment shows that regular public schools can provide quality education just as the PLS schools if they are given the same advantages as those bestowed on the PLS schools, such as being able to receive more government funding, more qualified teachers, and more training for less-qualified teachers in Liberia.

Together with other initiatives, the PLS program was part of a four-year plan called G2B-ESP, which was established in 2016 by the Ministry of Education (MoE) of Liberia to improve the quality of education from 2017 to 2021 (Ministry of Education in Republic of Liberia, 2016). The PLS program is currently on-going and has shown that it does improve student performance, but its success has come with a high price tag for the government (Laws, 2018; Romero et al., 2017). According to the Ministry of Education in Republic of Liberia (2016), the four-year plan's primary goals were to ensure that every child could attend a school within their neighborhood, increase the number of qualified teachers, lower dropout rates and the number of over-age students, provide schools with adequate supplies, and make sure that schools endow students with employment skills. To accomplish these goals, the MoE has been building more schools with effective sanitation programs, training more teachers and increasing their access to high-quality instructional materials, and creating programs that offer alternative opportunities to over-age students and individuals who have dropped out of school (Ministry of Education in Republic of Liberia, 2016). The MoE has also been working on standardizing the curriculum nationally, monitoring school administrators and staff to make sure they are adhering to practices that promote better learning outcomes for students, and so on. Despite these efforts, about half of teachers in Liberia are still unqualified (Ministry of Education in Republic of Liberia, 2016). Furthermore, the COVID-19 pandemic has led to the postponement of many initiatives. As a result, it will probably take more than four years for the plan to come to complete fruition.

2.6 Technology and Interactive Learning in Education

Contemporary interactive learning platforms, such as Learning Equality's Kolibri, World Possible's RACHEL, Ustad Mobile, and E-learning for Kids, discussed in this section are all examples of m-learning. M-learning is a form of learning that utilizes mobile or portable electronics like smartphones, tablets, and laptops, and m-learning is an extension of e-learning, which involves using any electronic device to teach and learn educational information (Ozuorcun & Tabak, 2012). According to Ozuorcun and Tabak (2012), e-learning is learner-centered, which means that it places students in charge of their learning experience by giving them the freedom to learn at their own pace in any location, while also offering them access to diverse information beyond the classroom or curriculum. In addition, it makes it easier for students to collaborate than traditional education may allow (Ozuorcun & Tabak, 2012).

To combat factors such as lack of Internet access and digital education tools that contribute to low-quality education, but which are not the focus of MoE, many non-profit, non-government organizations have developed free and low-cost offline e-learning tools. Similar to HVK’s Lab-in-a-Box, the Learning Equality organization has made education more accessible for institutions such as “rural schools, refugee camps, orphanages" with little to no access to the Internet through their free offline software-based library named Kolibri, which can be downloaded on low-cost computers (Windows, Apple, and Linux) and Android tablets (Kolibri, n.d.-a; Learning Equality, n.d). The Kolibri library contains a diverse array of open-source educational resources, from textbooks and other books to Khan Academy and Wikipedia. Kolibri is available in many languages and can be accessed in and out of the classroom by students all around the globe. Both instructors and students can organize, add, and remove content to suit their curriculum or learning needs and preferences (Kolibri, n.d.-a). With supporters such as Google.org, the William and Flora Hewlett Foundation, and BrowserStack, and with partners like UNICEF, Khan Academy, and UNHCR (the UN Refugee Agency), Learning Equality has been able to impact “200 countries and territories, reaching an estimated 4.5 million learners, in contexts as varied as rural schools, orphanages, community centers, refugee camps, prisons, and homes" (Learning Equality, n.d-a).

Similar to the Learning Equality organization, the World Possible organization aims to close the knowledge gap. It has successfully developed an offline portal similar to the Lab-in-a-Box. The creation of the Lab-in-a-Box was inspired by a platform called Remote Area Community Hotspot for Education and Learning (RACHEL), which was developed by the World Possible organization in Irvine, California (GuideStar, n.d.). RACHEL is a portable server with a large offline database already installed called OER2GO. This contains educational resources such as Khan Academy, Wikipedia, Moodle, and many other resources that can all be accessed and downloaded offline (World Possible, n.d.-a). In 2016, the organization distributed these portals to 47 countries, including Guatemala, Kenya, Ghana, Sierra Leone, and Tanzania, as well as 14 state correctional facilities in the United States. By 2017, there were at least 500,000 learners around the world (World Possible, n.d.-b).

The Ustad Mobile app has also tackled the issue of access to educational resources. Anyone can find the app on Google Play or the Apple App Store. Based in Afghanistan and recognized by the BBC and UNESCO as a powerful offline educational tool, the Ustad Mobile app can be accessed both online and offline on mobile phones (including non-smart phones, like old Nokia phones) by Afghan students of all ages living in areas without Internet access. The app contains a vast library of educational resources such as Khan Academy, books, and games, among others. It allows teachers to add and grade assignments and students to work on and submit the assignments. These many functions are accessible with its free plan (Ustad Mobile, n.d.). Ustad Mobile has made education more accessible for students in developing nations.

There have been many non-profit organizations looking to help educate young African children through e-learning tools. Estimated to have impacted over 16 million children with their offline educational platform across Africa, E-learning for Kids is a non-profit organization providing free, fun, and offline curriculum-based quality primary education to all children worldwide (E-learning for Kids, n.d.). The foundation was launched in the United States in 2004 and in the Netherlands in 2007 (E-learning for Kids, n.d.). The organization uses their platform to teach many different subjects to their students. With E-learning for Kids, the organization offers free, best-in-class curriculum based learning for children ages 5-12 in math & science, including environmental skills, health, and life skills (E-learning for Kids, n.d.). The courses on the platform are created based on the curriculum of the International Baccalaureate, which is a program internationally accepted by nearly 140 countries (E-learning for Kids, n.d.). Also, like Ustad Mobile, RACHEL and other platforms, E-learning for Kids is a software that can be accessed on a wide variety of devices.

2.7 Conclusion

Education is a basic right for every human. However, it can be difficult to provide everyone access to education in a country like Liberia, which has had many struggles in the past 30 years as a result of corruption and two civil wars. These factors and events considerably damaged the country's infrastructure, economy, and the education system. These monumental setbacks were then exacerbated by the Ebola outbreak, and more recently, the COVID-19 pandemic. As a result, it has been difficult for Liberia to establish a successful education system. HVK grants young students in Liberia opportunities to learn on an established platform and receive quality education. Our project goal was to refine the Lab-in-a-Box system, so that students and teachers can have a better user experience. The next chapter, Methodology, discusses the approaches we took to accomplish our objectives, such as interviews, surveys, secondary research, content analysis and focus groups.

3 METHODOLOGY

The prime goal of the HVK Children's Foundation is to provide science, technology, engineering, arts, and mathematics (STEAM) education in low-resource schools in poor communities in Liberia. Liberia has endured many hardships caused by major historical events that made a lifelong impact on the education system and economy, and which led to high poverty rates. For that reason, children are out-of-school or underperforming, half of the teachers are unqualified, and schools are underfunded. With the help of GSAP and donations from sponsors and partners, HVK keeps children in school and improves the quality of education. So far, HVK has helped more than 1,000 students at six different schools in Liberia, trained at least 20 teachers, and donated the Lab-in-a-Box systems and 34 sets of tablets. However, only three of six schools with which HVK is working in Liberia have access to the devices and portals of the Lab-in-a-Box for learning. Even though HVK has made a noteworthy contribution to the Liberian education system and influenced many lives, the Lab-in-a-box and its content are in need of improvement to make it more user-friendly, organized, and up-to-date.

3.1 Goal and Objectives

The HVK Children's Foundation aims to close the knowledge gap between children in poor communities in Liberia by increasing access to high-quality education through the Lab-in-a-Box portal. By installing portals and tablets in schools, students and teachers can access resources offline to improve student performance and teaching quality. To improve the user experience of the Lab-in-a-Box portal, we developed and addressed the following four objectives:

1. Understanding the portal and current curriculum in Liberia.
2. Improving the bandwidth and the battery capacity of the system.
3. Updating the portal with new and relevant content and organizing them in a new content management platform with a login system and monitoring system.
4. Developing training programs for teachers on setting up and operating the portal.

We conducted interviews and surveys to understand the project scope, expectations of HVK, objectives, and latest user experiences and concerns with the portal. We conducted experiments and analyses to test and pinpoint the issues with the wireless connection and the power system of the Lab-in-a-Box. We relied heavily on secondary research throughout this project and found a potential content management system that could replace the GSAP portal. We searched and selected new academic content to add based on the requests from the interviews and the surveys and reorganized those content in a new content management platform. Lastly, we created tutorial videos and instruction manual pamphlets to train teachers in setting up and operating the Lab-in-a-Box portal and conducted a focus group study to improve our training platform.

We organized concerns from our sponsor regarding the Lab-in-a-Box into two groups of required improvements (Table 4): hardware and software. In each group, we listed specifically what the issues were and how we tackled those.

Table 4. *Concerns of hardware and software and our plans to tackle each issue*

Hardware Improvements	**Software Improvements**
Improve battery life and usage analytics by providing an overall summary of the capacity and limitations of the solar panels	Add new content and remove old content per sponsor's request and based on survey responses pertaining to user experience
Improve size of bandwidth for the portal by changing device settings and checking the data transfer speed between the router and devices	Add a system to monitor user patterns such as frequency and duration of visiting certain content
Learn and understand current system storage capacity and additional storage needed for updates to the Lab-in-a-box	Create a step-by-step instruction manual pamphlet and tutorial videos to train teachers on how to set up and operate the Lab-in-a-box
Learn how the Lab-in-a-Box works on the technical side (hands-on experience) by setting up the system, exploring it, and reaching out to those who were involved in creating the Lab-in-a-Box for their insight	Find a program to add a search bar tool for convenience of finding content more quickly

3.2 Objective 1: Understanding the Lab-in-a-Box and the Current Curriculum in Liberia

To achieve our goals, we needed to grasp the big picture of the problem. We first interviewed the CEO and co-founder of HVK Children's Foundation (Appendix A) to understand the objectives of the project and the mission of the organization and the Lab-in-a-Box program. Although the literature review chapter helped us to understand the underlying issues and history of Liberia, we had insufficient technical knowledge about the Lab-in-a-Box and users' experience to achieve our goals. With the assistance of the CEO and co-founder of HVK Children's Foundation, we set up a one-on-one virtual interview (Appendix B) with the Lab-in-a-Box personnel who monitored the system at the three different schools that use the Lab-in-a-Box in Liberia. The interview with the personnel in Liberia allowed us to hear first-hand accounts of using the Lab-in-a-Box. This person also helped distribute our surveys to 28 students and 20 teachers at three different schools that were using the Lab-in-a-Box (Appendix C). Those teachers and students were chosen randomly by the personnel of the Lab-in-a-Box in Liberia.

3.3 Objective 2: Improving Wireless Connection and Battery Life

After analyzing the interview notes collected from our interviews (Appendices D & E) and survey responses (Appendix C) in Objective 1, we had a clear understanding of how to accomplish Objective 2. Specifically, we understood what improvements needed to be made to the wireless connection between devices and the Lab-in-a-Box and the battery capacity.

We investigated connectivity issues between the Lab-in-a-Box and devices. We conducted secondary research to learn about router specifications that significantly influence the experience of using a router. We researched the specifications of the RavPower travel router used by HVK, a TP-LINK AC1750 home router, and a Raspberry Pi 4. We summarized the specifications of three devices, which we obtained from either its manual or website. Next, we researched the meaning and impact of each specification on the user experience of the router. With an understanding of wireless technology and terminology, we narrowed down to what we believed the issue was and conducted the bandwidth experiment.

From observing the physical size along with the specifications of the RavPower travel router, we hypothesized that devices often disconnected because small routers with outdated wireless technology usually have smaller bandwidth and take longer to transfer large files. We had three candidates for bandwidth tests: the RavPower travel router, TP-LINK AC1750, and Raspberry Pi 4 with 8 GB RAM. The RavPower travel router and TP-LINK AC1750 did not require configuration. Only the Raspberry Pi required configuration.

A Raspberry Pi is an inexpensive, credit card sized, easily programmable computer. Using its "blank canvas" of a system, the Raspberry Pi can be set up as a server to distribute content over a wireless network for a range of 25-30 devices, depending on the model (Learning Equality, 2019). Setting up the Raspberry Pi with the Kolibri operating system (OS) as a server was a straightforward process (Appendices F & G). This fully set up Raspberry Pi functions the same way as the current Lab-in-a-Box portal but with a much easier set up and access point.

To obtain the maximum bandwidth of each router, we connected the portal to our internet modem. The 64GB USB flash drive was plugged into the router. It required the presence of an internet connection to be able to get the information of download speed and upload speed produced by the router. Once our laptop wirelessly connected to the portal and we could access the Internet because of the modem, we downloaded and used the SpeedTest software created by Ookla to acquire the download and upload speeds between the portal and our laptop at four different conditions, starting with no content being open, then 10 content, 20 content, and 30 content (Ookla, n.d.). Our sponsor wanted to have at least 30 devices to be able to connect to the router in schools in Liberia, so we simulated 30 devices connecting to the router by opening 30 content simultaneously. This allowed us to understand how much content in the USB flash drive the router could transfer to the laptop after being opened on the device before the connection would crash. We repeated the same procedure for the TP-LINK AC1750 home router (Figure 3) and Raspberry Pi 4 (Figure 4). While the SpeedTest software worked on the RavPower and TP-LINK AC1750, it did not work on the Raspberry Pi 4 because of the firewall. Therefore, we conducted secondary research to understand the specifications of the Raspberry Pi 4 with 8GB RAM model. Based on these bandwidth tests, we created a comparison list for HVK with potential options of more recent low-cost routers, including their pros and cons.

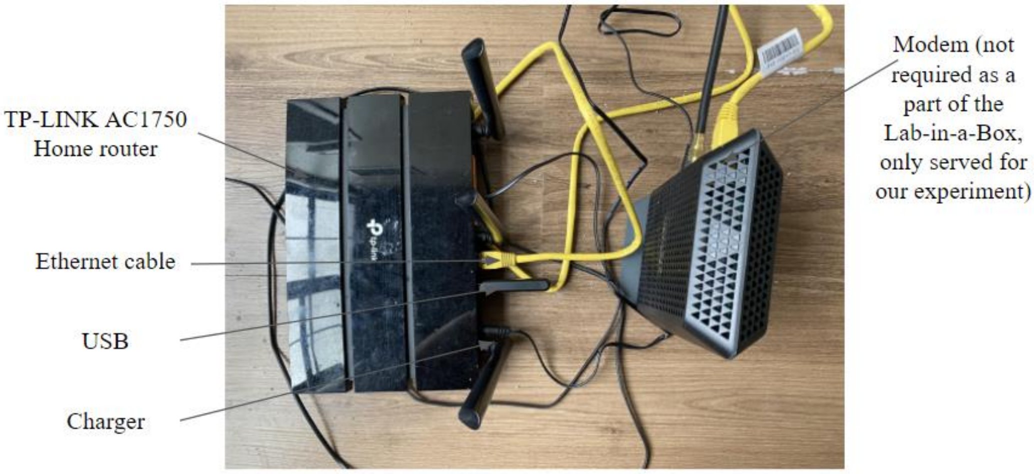

Figure 3. The setup of the TP-LINK AC1750 home router with the flash drive to the modem for the bandwidth test

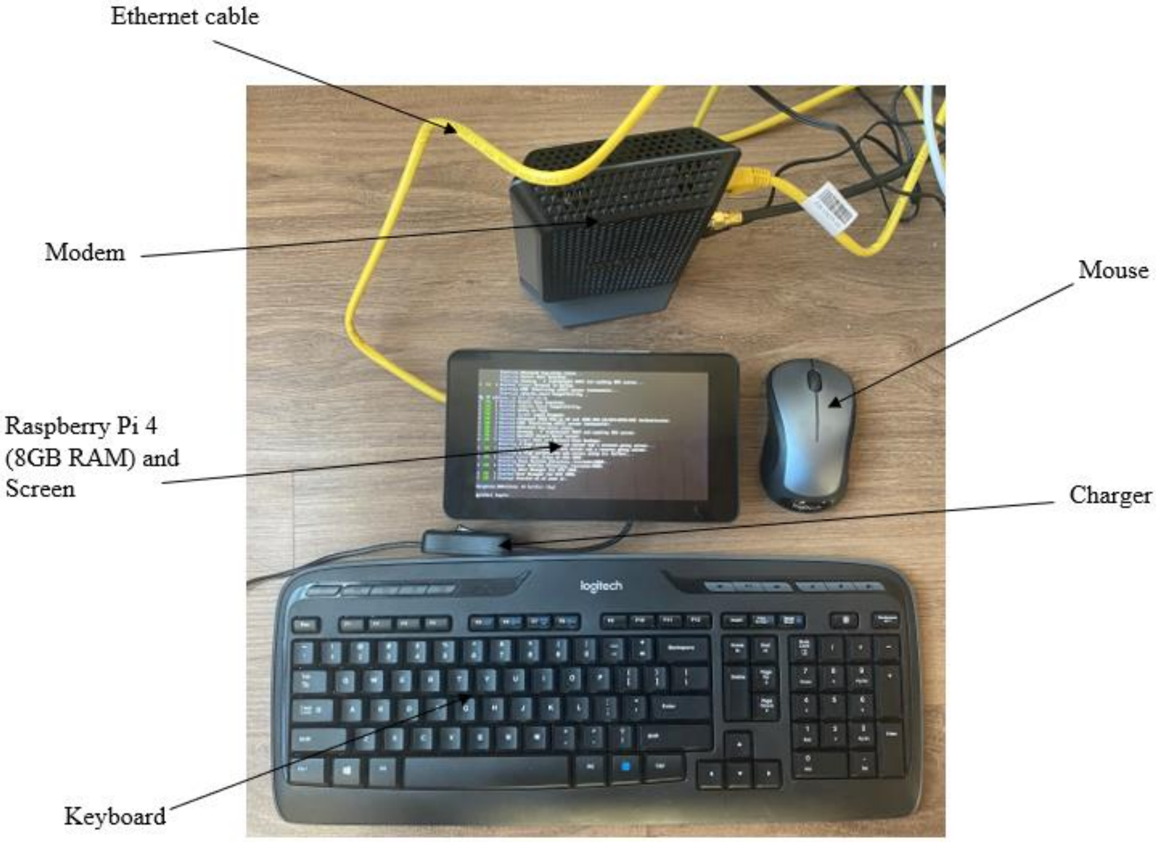

Figure 4. The setup of the Raspberry Pi 4 with the flash drive to the modem for the bandwidth test

To improve the battery capacity of the Lab-in-a-Box, we had to gain an understanding of the entire Lab-in-a-Box setup. To understand the limitations and capabilities of the Lab-in-a-box system, we had to learn the ins and outs of how the power side of the system worked by assembling the entire Lab-in-the-box. To perform a power analysis of the system, we examined the solar panel, car battery, and power inverter. We observed the solar panel to see if the solar panel array could be altered in a way to make it produce more power than it already produced. With the solar panel there was a small panel on the back giving the power diagnostics of the device to further understand the solar panel. We observed the battery to find its overall power diagnostics. The label sticker on the battery displayed diagnostics, including the voltage and amp-hours, which helped us understand the limitations of the battery. We then found the input and output voltages on the label sticker attached to the power inverter to understand how much power it was taking away from the battery. We developed an overall power analysis of the part to get a power inverter estimate of power usage. All of these steps helped us to better understand the Lab-in-a-Box set-up, the limitations of its solar panel, car battery, and power inverter.

3.4 Objective 3: Updating the Portal with New Content and Reorganizing this Content in a Content Management Platform with a Login System and Monitoring System

For Objective 3, using interviews and survey responses from Objective 1, we updated the portal with new content. We were asked by our sponsor to reorganize Lab-in-a-Box's offline web-based portal in addition to adding new content to the system, to make it more current and organized.

First, we attempted to address how both students and teachers accessed the portal. The GSAP portal does not allow teachers and students to have individual log in identification. Consequently, user identity (student/teacher), frequency (how often a user logs on and visits certain content), and duration (time spent using the portal per each login) could not be ascertained. For example, this precluded determining which activities in the portal students were more interested in (that is, frequently used) and which content should be modified or completely replaced with new content. We conducted secondary research to find new content management platforms that had a login system in which teachers and students created individual accounts and a monitoring system to track the user activity and the learning progress before adding new content. Our sponsor looked at giving new life to the GSAP's HTML web pages by re-designing the appearance of those web pages to make them more appealing and better represent HVK and re-organizing both new and current content into new HVK's HTML web pages, and yet still have a login system and a monitoring system. We familiarized ourselves with all the features of the GSAP's HTML web pages. Given the limitations of the GSAP's HTML web pages, we conducted secondary research to find new content management options that allowed customization and met other objectives such as having a login system and a monitoring system. After finding potential content management options, which included Nicepage software and the Kolibri platform by Learning Equality, we tested out all the features and took note of the pros and cons that each option had.

For the Nicepage software, we created a prototype homepage with a new design that represented HVK to test and explore all of the features and perform a test run of the content that we added to see if the content would open up similar to GSAP. For the Kolibri platform, we created an account using our personal email address to test out all the features and perform a test run of the GSAP content that we uploaded. We compiled all the features that each content management option provided into a comparison table to compare with the original GSAP portal. This allowed the sponsor to narrow down the choices based on their pros and cons and pick a possible replacement for the GSAP portal that fits the needs of the organization.

After we found that the sponsor would like to proceed with Kolibri, we made a comparison table to understand what content in the GSAP portal was available and not available in the Kolibri database and OER2GO (Appendix H). In HVK's Kolibri Studio account, we only added new content from the Kolibri database and organized them by grades. There were six channels on the homepage after logging in: Early Childhood, Primary School, Middle School, High School, College, and Teachers. In each channel, there were folders designated for each subject (math, science, English, Humanities & Arts, others). In each of those folders, the content for that particular subject and age group could be found. We did not select and download content from OER2GO since World Possible restricted most of their content from non-buyers and only allowed few contents to be downloaded. Some of the downloadable content in OER2GO was also available in Kolibri. For the entirely new content that was not available on both Kolibri and OER2GO, we went through the possible content to be added by watching or reading it and conducting secondary research on those sources to check for accuracy. We compiled a list of website links to new open-source history content on Liberia and Africa in a Google Spreadsheet and forwarded it to our sponsor to approve, but we did not add content from those websites to Kolibri. As we updated and added content to the HVK's Kolibri Studio account, we also created another Google spreadsheet and shared it with the sponsor so that the team and the sponsor were able track which content was uploaded successfully and which was not, including the name and the location of the content (Appendix I).

After we found out that we did not have enough space to upload GSAP portal's files and new African and Liberian content to HVK's Kolibri Studio account, we filled out a form on the Kolibri website to request for an additional 10GB. While we were waiting for the approval, we continued to add content directly from Kolibri library. Unfortunately, with a limited amount of time and insufficient cloud storage, we only were able to have Kolibri content added to HVK's Kolibri Studio account.

3.5 Objective 4: Developing an effective teacher training platform for the Lab-in-a-Box

After we achieved Objective 3, we shifted our focus to Objective 4 which was finding a way to develop effective training platforms to instruct teachers on setting up and operating the Lab-in-a-Box. By this point in our objectives, we had a good understanding of the Lab-in-a-Box to be able to teach others how to set up and use it. The problem was finding effective and easy ways for teachers to understand our method of teaching. To ensure our familiarity with the Lab-in-a-Box did not affect the training materials, we approached the training materials with a novice audience in mind.

To mitigate the risk of our bias spilling into our instructions, we had three methods to get rid of it. The first method was to conduct secondary research and study how to improve our instructions. Our biggest focus when developing the training programs was clear and concise instructions. The second method was an interview with a WPI instructional media specialist with expertise in creating interactive instructional materials through a wide range of media tools (Appendices J & K). Communication was important when creating this set of instructions because if we were not able to clearly communicate the instructions to the teachers without us being physically present, it would cause confusion about operating the Lab-in-a-Box. The last method was a focus group to ascertain and address the strengths and weaknesses of the training programs based on feedback from participants after reading or watching the programs.

We created two tutorial videos. The first one demonstrated how to set up the hardware of the Lab-in-a-Box, and the other how to access and use the Lab-in-a-Box portal once the whole system is set up. In the first video, we took pictures of all required equipment and tools and then filmed each step. Then we recorded voice overs using the smartphone to describe the processes of each step. We used Camtasia to edit, make annotations, and arrange all the videos and voice recording files in the correct order to produce one complete video. In the second video, we video-recorded the computer's screen using Bandicam software as we wirelessly connected from a computer to the system's router, then opened the portal from a web browser, and went through multiple steps of clicking on different web folders to get to the portals main homepage, where all the content were categorically organized and could be easily accessed.

We designed a supplemental pamphlet using Piktochart. Based on the advice that we received from the interview with the instructor, we made the instructions in the pamphlet more detailed to avoid confusion. The steps in the pamphlet mirror the steps in the video so that teachers could watch the video and read the pamphlet at the same time. We also added pictures to the pamphlet to illustrate each step.

The final step was to hold a focus group on the tutorial videos and pamphlet we created. Focus groups are a method to gather feedback from consumers or users about products or services (Rees, n.d.). We were not able to conduct our focus group with teachers in Liberia due to COVID-19 restrictions and limited access to the Internet in Liberia. Instead we conducted a focus group over Zoom with students and staff at WPI. The participants watched the tutorial videos and read the pamphlet for comprehension of the steps shown and described. After performing those tasks, they completed two online surveys, one for the video and one for the pamphlet, to evaluate and give feedback on what was confusing to them and what they particularly liked (Appendix L). We analyzed the survey responses for the video and the pamphlet by themes such as organization, engagement, information, and format, and summarized only key points of the responses. Based on the survey responses, we revised the training platforms.

Ethical Considerations

Before conducting any interview, handing out any survey, and completing the participant focus group, we informed the research subjects that their participation was voluntary and anonymous, and that they could withdraw at any time. Before performing any of the procedures, we explicitly asked the subjects to give their informed consent by presenting them with the informed consent script that can be found in Appendix M.

4 RESULTS & ANALYSIS

In this chapter we present our results and analysis which are organized by theme. First, we will discuss the GSAP portal and how it lacked new content, a login system, and a monitoring system. Then we will discuss findings on connectivity issues stemming from bandwidth issues in the current system. Next, we will discuss the power issues within the system and how the root cause is unknown. Lastly, we will discuss the findings regarding teachers' and students' level of confidence with setting up and operating the Lab-in-a-Box and the deliverables of the training program.

4.1 GSAP Portal Lacked New Content, a Login System, and a Monitoring System

Our interviews identified the need for additional content on Africa and Liberia. Both teachers' and students' survey responses showed their content preferences that helped us in updating the portal. 65% of teachers indicated they taught science-related content the most, 20% said English, and the remaining 15% said math (Figure 5). Students appeared to prefer all subjects roughly equally (Figure 6). Approximately 65% of teachers said they wanted more videos on the Portal, saying that they make it easier to illustrate lessons and help students better understand. All of this informed us to focus on more STEM (science, technology, English, and math) content with video components to them when adding content to the portal.

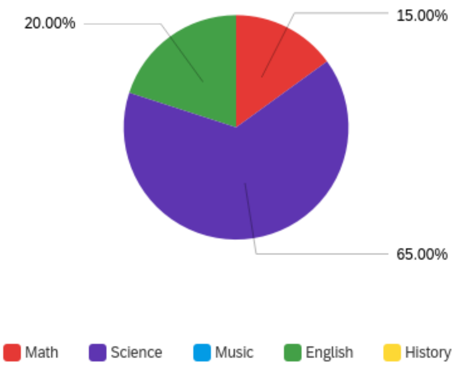

Figure 5. Teachers' most used subject

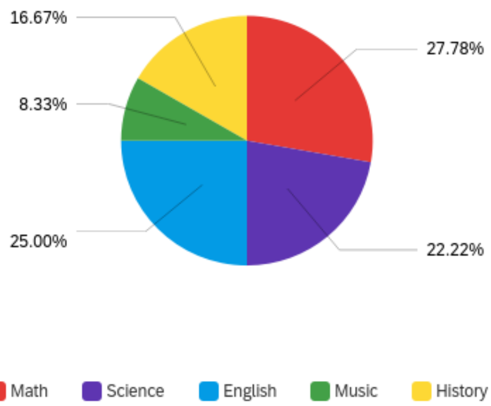

Figure 6. Students' favorite subjects

The current GSAP system needs new content and new features including a login system and a monitoring system. Both interviewees identified a need for separate login pages for students and teachers, a monitoring system to keep track of users, and a more organized database (Appendices D & E). We found that Nicepage software was easy to use and able to export web pages as HTML files. Moreover, it acted similarly to GSAP's HTML web pages with which our sponsor was already familiar. We developed a prototype of a new HTML web page by using Nicepage (Figure 7). We found that Kolibri by Learning Equality has a database that is similar to World Possible' RACHEL, in which both platforms wirelessly distribute learning materials in the offline setting and are easy to set up and use. More importantly, not only was the Kolibri library (Figure 8) neat, fair, organized, and free to download to our own devices, but it also allowed for separate logins and content monitoring while Nicepage did not. The features of the three platforms are briefly summarized and compared in Table 5.

Figure 7. The homepage of the HVK portal prototype using Nicepage

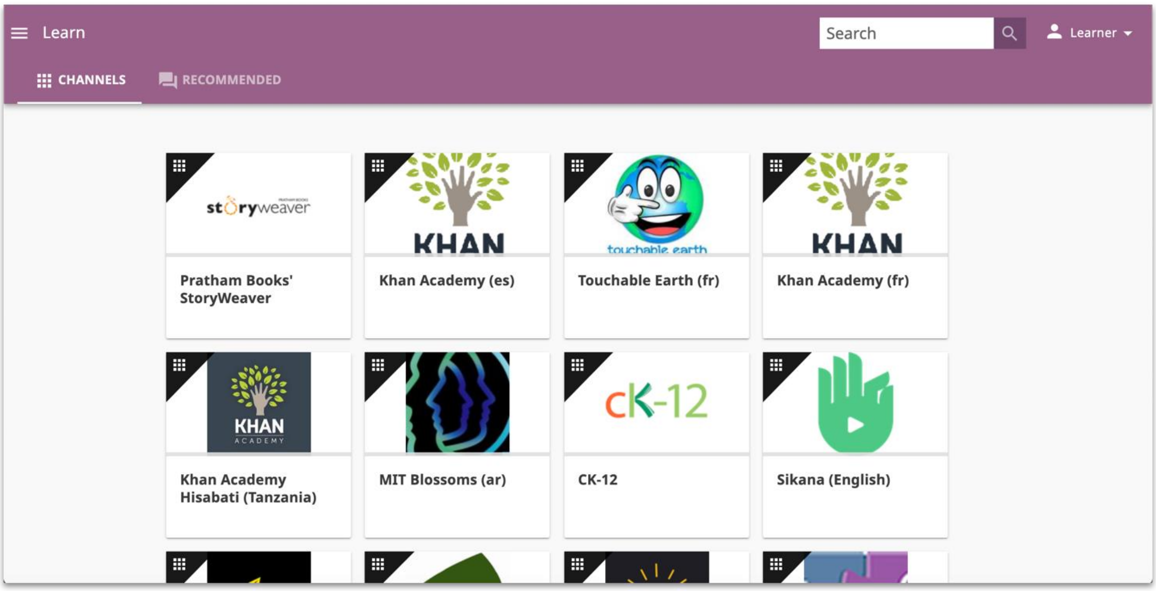

Figure 8. Kolibri customizable library (Kolibri, n.d.-a)

Table 5. *Three content management options*

	GSAP	HTML WEBSITE (NICEPAGE)	KOLIBRI
PRICE	FREE	At least $4.95/month	FREE
CODING REQUIREMENT	Yes	Maybe	No (Desktop), Yes (Raspberry pi)
STORAGE TYPE	USB	USB/exHDD/ex SSD	SD/USB/exHDD/exSSD
DATA	Depends USB	Depends USB	Depends SSD or Hard Drive (Windows version) or depends SD card or USB or Ex HDD/SSD (Raspberry pi)
UPDATE CONTENT	Find by yourself	Find by yourself	Find by yourself/ Use their contents
SEPARATED LOGIN PAGE	No	No	Yes
ASSIGNMENTS/QUIZZES	No	No	Yes
CLASSROOM MANAGEMENT SYS	No	No	Yes
MONITORING /TRACKING SYS	No	No	Yes
CUSTOMIZABLE	No	Yes	No
OTHER REQUIRED EQUIPMENTS	USB, Router, Charger	USB, Router, Charger	Device (replaced USB) OR Raspberry pi (with SD/USB/ex HDD or SSD), Router, Charger
TECHNICAL SUPPORT	No	No	Yes
HTTRACK REQUIREMENT	Yes	Yes	No
WEBSITE VERSION	Laptops, tablets	Laptops, tablets, phones	Laptops, tablets, phones

After presenting the comparison table and discussing it with our sponsor, they agreed to replace the GSAP portal with Kolibri for the Lab-in-a-Box. Both Kolibri and RACHEL libraries shared similar content such as Khan Academy and CK-12. We found that Khan Academy provided by Kolibri (also called KA-Lite) occupied 54GB while CK-12 provided by Kolibri occupied 6GB. As we neared the end of our study, the total size of content in the Kolibri Studio account was 316GB. Our sponsor was currently using a 64GB flash drive, which was not enough for having Kolibri content, GSAP portal content, and new content that we added later. Additional storage would need to be added to accommodate new content.

4.2 Connectivity Issues Stem from Bandwidth Issues in the Current System

From the interviews with the Founder of HVK Children's Foundation and the personnel of the Lab-in-a-Box in Liberia we learned how often devices are disconnected from the Lab-in-a-Box. When asked how often devices disconnected from the portal, 55% of teachers answered "sometimes" and 35% said "about half the time," which demonstrated the importance of improving the wireless connection between devices and the portal (Figure 9).

Students had the same sentiment as teachers concerning how often devices disconnected from the portal (Figure 10). Another question in the teachers' survey showed that 18 out of 20 teachers identified the main concern was the connectivity between devices and the portal.

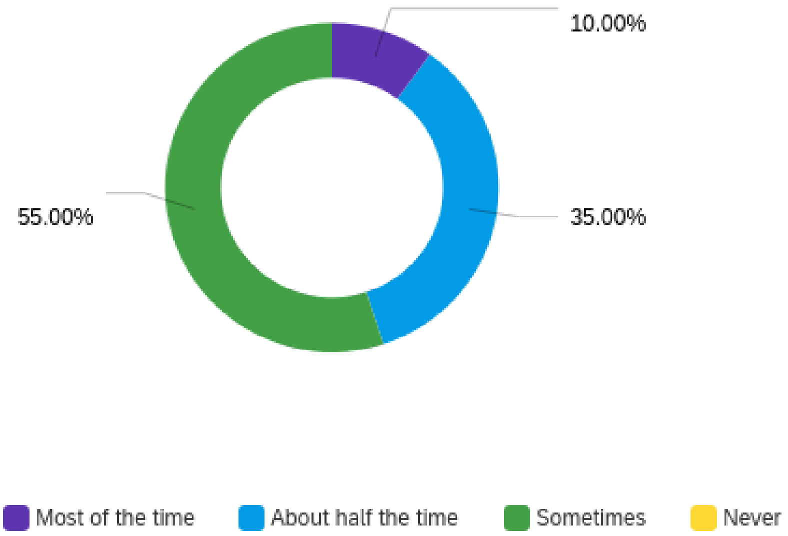

Figure 9. Teachers' responses about the connectivity of the Lab-in-a-Box.

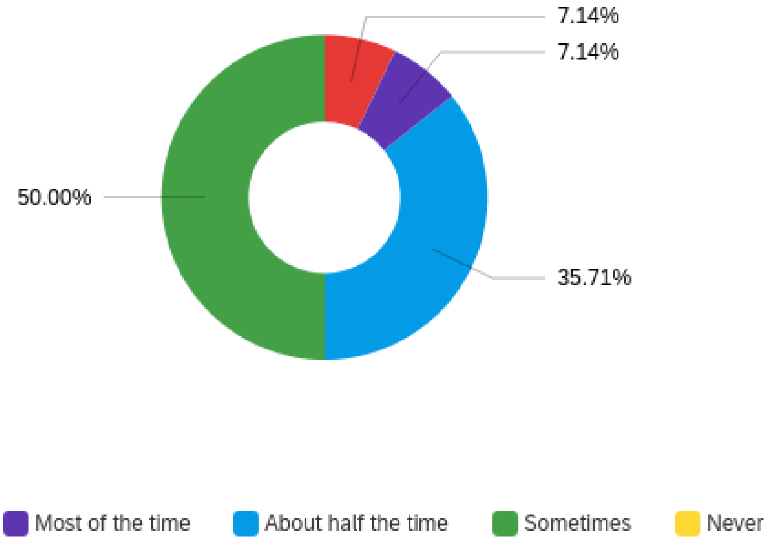

Figure 10. Students' responses about connectivity issues.

The Lab-in-a-Box personnel in Liberia stated that in one classroom five devices could simultaneously connect to the RavPower travel router to access the content in the USB and added that the disconnection happened every 5 minutes (Appendix E). Our understanding of the wireless standards and data transfer rate of the RavPower travel router led us to believe that the frequent disconnection was caused by low bandwidth. Five important specifications can influence the effectiveness of a router, which are wireless standards, antennas, security, speed (bandwidth), and frequency channels (Eero, 2016). Based on RavPower's product manual and the websites for TP-LINK AC1750 and Raspberry Pi 4, we found and focused only on information about the frequency band, wireless standards, and data transfer rate as shown in Table 6 below.

Table 6. *The specifications of the RavPower, TP-LINK AC1750 & Raspberry Pi 4*

Specifications	RavPower	TP-LINK AC1750	Raspberry Pi 4
Frequency Band	2.4GHz	2.4GHz & 5GHz	2.4GHz & 5GHz
Wireless Standards	IEEE 802.11b/g/n	IEEE 802.11ac	IEEE 802.11b/g/n/ac
Data Transfer Rate	300Mbps	1350-1750Mbps	950Mbps

Note. The data for RavPower are from "Product Diagram; Package Contents; Specifications - Ravpower RP-WD008 User Manual", by ManualsLib, n.d., p.3, (https://www.manualslib.com/manual/1573885/Ravpower-Rp-Wd008.html#manual). The data for TP-LINK AC1750 are from "AC1750 Wireless Dual Band Gigabit Router", by TP-LINK, n.d., (https://www.tp-link.com/us/home-networking/wifi-router/archer-c7/). The data for Raspberry Pi 4 are from "Raspberry Pi 4 specs and benchmarks", by Rob Zwetsloot, n.d., (https://magpi.raspberrypi.org/articles/raspberry-pi-4-specs-benchmarks?fbclid=IwAR0aBSkW_4dwxLPcNvdAIW7rccnfZXqrlr_swb3TlCv8aCpfmUD59oAGRAY).

We found that the RavPower travel power did not produce enough bandwidth for multiple devices to connect to the portal at the same time. Based on the advertised specifications, the travel router's bandwidth should have been 300 Mbps (Table 6 above), which depended on both the frequency channels and wireless standards. Table 7 below shows the bandwidth test results in comparing the RavPower travel router, TP-LINK AC1750, and Raspberry Pi 4 at four different conditions. When no content was opened on the device, the download speed of the TP-LINK AC1750 home router was already higher than the RavPower travel router by at least three times. While the download speed of the travel router reached close to 0 Mbps at 30 content, the download speed of the TP-LINK AC1750 throughout the experiment from 0 content to 30 content was stable at approximately 115 Mbps. With these results, we concluded that the RavPower router could not support at least 30 devices that our sponsor would like to have while the TP-LINK AC1750 was able to.

Table 7. *The data transfer rate of the RavPower travel router and the TP-LINK AC1750 at four different conditions*

Routers	0 content	10 content	20 content	30 content
RavPower	49.3 Mbps	51.7 Mbps	33.6 Mbps	0.3 Mbps
TP-LINK AC1750	115.6 Mbps	115.4 Mbps	115.9 Mbps	115.6 Mbps
Raspberry Pi 4	Unable to conduct the test due to firewall			

Unfortunately, the Raspberry Pi 4 only allowed users to import new content in the presence of the Internet. As can be seen in Table 7 above, we were unable to use the SpeedTest software to perform a bandwidth for the Raspberry Pi. We found that Learning Equality, which developed Kolibri, also reminded the users on their website that the Raspberry Pi can receive Internet connection when connected to a modem with Internet but will not provide the Internet to any devices that are connected to the Raspberry Pi (Kolibri, n.d.-b). We concluded that the Kolibri OS had a firewall to impose such a limitation. However, even without the bandwidth test, we learned from both Learning Equality and the specifications of Raspberry Pi's that the Raspberry Pi 3+ and 4 can handle 20-30 devices (Learning Equality, 2019). When we successfully loaded Kolibri OS on a Raspberry Pi 4 with an 8GB RAM, it worked as smoothly as advertised as we were able to connect it to seven devices and open content such as HD videos simultaneously. Even on one device with 30 opened content, it ran smoothly as well.

4.3 Teachers and Lab-in-Box Personnel Identified Power Issues within the System and the Root Cause is Unknown

Power issues were raised in both interviews and surveys. From the survey responses, two out of 20 teachers commented about the lack of sufficient power to power the entire Lab-in-a-Box system. In our power analysis, we determined that the solar panel supplied ample power to the battery at a maximum power voltage of 18 Vpm (Volts per minute), at a steady

100 watts with a power current of 5.56 amps. This means when the solar panel is at its full capacity, it could produce 100 Wh if it is in the sunlight. This should provide enough electricity to fully recharge the battery and operate the entire system efficiently. We then found that the battery voltage was 12 V at 100 Ah, putting the overall power consumption capabilities of the battery at 1200 Wh (or 1.2 kWh). A power inverter converts DC voltage to AC voltage (created by the solar panel, in our case), which is a process that requires a substantial amount of power. We found that the power inverter could produce 110 V AC using 25.6 amps at 10-15 V consuming a maximum of 76.8 Wh. Based on these findings, we concluded that the system was running at optimal power capacity and we could not determine the exact cause of the power issues solely from this power analysis.

4.4 Teachers Were not Confident with Setting Up and Operating the Lab-in-a-Box.

From the interviews with the Founder of HVK and the Lab-in-a-Box personnel, we found a need for a training program for both hardware and software aspects of the Lab-in-a-Box. From the teacher surveys, only 55% of teachers responded that they were extremely comfortable with operating the Lab-in-a-Box while 35% found it neither comfortable nor uncomfortable (Figure 11).

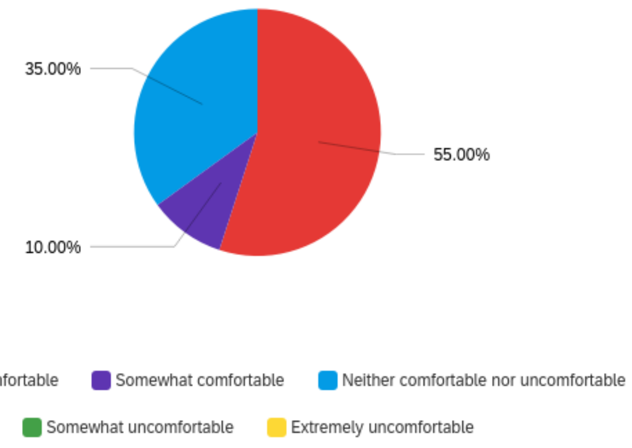

Figure 11. Teachers' responses about their confidence on operating the Lab-in-a-Box

Our final deliverables include the tutorial video and pamphlet (Appendix I). These training programs will be used to teach the faculty in the schools to set up their own system and operate it.

Before finalizing these deliverables, we learned about and addressed the strengths and weaknesses of the training programs based on survey responses from the participants of the focus group study we conducted (Appendix N). For the tutorial video, the participants noted that the video had enough information without repetition but suggested we add background music to better engage viewers, rearrange the order of some steps for better organization, shorten prolonged pauses between steps, and make additional videos to explain steps that may require more explanation to be grasped such as how to strip an electrical wire. Most participants responded that the pamphlet, overall, was organized and engaging but recommended we use more close-ups for web browser icons and others (the Lab-in-a-Box portal can be accessed using any web browser and some staff may not know all the web browsers out there), emphasize safety precautions (for example, wrapping more electrical tape around copper portions of wire connect to the battery), add page numbers, use consistent colors and dyslexic-friendly font (or any font that is more spaced) to increase ease of reading. These suggestions helped us to see gaps in the training programs and, thanks to their specificity, we followed them to deliver more easy-to-read, comprehensible instructions.

5 RECOMMENDATIONS

Based on the results of our research, we recommend our sponsor invests in the following: replacing the GSAP portal with Kolibri, a Raspberry Pi 3 or 4 to implement Kolibri, a 512GBG microSD card for storage expansion, additional research to ascertain the actual cause of the power issues, estimating the amount of wire needed, and using the training programs we created to instruct the staff on how to properly set up and use the Lab-in-a-Box.

5.1 Replace the GSAP Portal with Kolibri.

We recommend replacing the GSAP portal with Kolibri because it has separate login pages for teachers and students, a monitoring system, a classroom management system, and a quiz and assignment system.

5.2 Use a Model 3 or 4 Raspberry Pi to Implement the Kolibri System

We recommend purchasing a Vilros Raspberry Pi 4 (8GB RAM) set with a touchscreen and a keyboard with a touchpad (Figure 12). The setting up of Kolibri server on the Raspberry Pi optimally works on Raspberry Pi 3 and newer. We recommend our sponsor to follow instructions in Appendices F & G for setting up Kolibri on the Raspberry Pi. The touchscreen with the Raspberry Pi attached to the backside and the keyboard with a touchpad are portable, which will allow teachers to bring it and move between classes without a need for purchasing another Raspberry Pi set.

Figure 12. Vilros Raspberry Pi 4 (8GB RAM) set with a touchscreen, keyboard, and touchpad

If our sponsor wants to keep the GSAP portal, we recommend that our sponsor invests in a better router to connect to more devices at faster speeds without connectivity issues. We prepared a chart of many different routers and brands with price comparison (see Table 8) to better suit the students and teachers. We recommend buying the TP-LINK AC1750 which has a data transfer rate of 1350-1750 Mbps as to suit the needs of the Lab-in-a-Box. With the ability to run at 1750 Mbps and connect to 20-30 devices at once, this router presents the best value for HVK. Appendix O has the links to all the server/router device options.

Table 8. *More recent router options Vs. Current router*

Device	TP-LINK AC1750	Tenda AC2100	ASUS AC2900	RavPower
COST	$56.99	$69.99	$161.62	Current Device
Mbps	1350-1750	1733-2033	2900	300
Range	1200ft	1200-1500ft	1200-1500ft	100ft
Watt hours	4.4	5.4	6.4	N/A
RAM	256-528MB	528MB	528MB	50-100MB
# of Device Capabilitie s	20-30	30-40	30-40	5-10

5.3 Use a 512GB MicroSD Card for Content Storage on the Raspberry Pi

We recommend that HVK invest in a Sandisk Extreme Micro 512GB microSD card (from Table 10) with a cost of $69.99 and a data transfer rate of 120Mbps to run the Kolibri system on the Raspberry Pi. This will allow HVK to expand the portal with new content. If HVK wants to continue to use the GSAP portal, we recommend our sponsor purchase a SanDisk 128GB Cruzer USB 2.0 Flash Drive with a cost of $17 and a data transfer rate of 100Mbps. Appendix P has the links to all the storage devices. Table 9 shows inexpensive low-storage devices with a storage capacity less than 500GB, whereas Table 10 lists inexpensive higher-storage devices with storage capacity over 500GB, which we recommend when 256 GB becomes insufficient.

Table 9. *Low-storage capacity storage devices.*

Low-Storage Devices	SanDisk 128GB Cruzer USB 2.0 Flash Drive	Samsung FIT Plus USB 3.1 Flash Drive 128GB	SanDisk 128GB Extreme SDXC UHS-I Card	Sandisk Extreme Micro SD 256GB
Cost	$17	$18	$23	$32.99
Data Transfer Rate	100 MBps (decent)	400 MBps (fast)	150 MBps (decent)	100MBps
Storage	128GB	128GB	128GB	256GB

Table 10. *High-storage capacity storage devices.*

High-Storage Devices	SanDisk 512GB Ultra microSDXC	F-Security Flash Drive	HixB Flash Drive	Seagate Hard Drive 4TB	Toshiba Hard Drive
Cost	$69.99	$41.99	$53.49	$96.99	$41.77
Data Transfer Rate	120 MBps	120 MBps	120 MBps	120 MBps	120 MBps
Storage	512GB	1TB	2TB	4TB	1TB

5.4 Conduct Additional Research to Determine Cause of Power Issues

From the overall power analysis, we could not determine the actual cause (or causes) of the power issues plaguing the Lab-in-a-Box system. We recommend that additional research be conducted to identify and address the cause (or causes) of power issues as fixing them would promote more learning by allowing students more usage time on the Lab-in-a-Box.

5.5 Measure the Physical Dimensions of Schools to Estimate Amount of Additional AWG Photovoltaic Wire Needed

While setting up the Lab-in-a-Box system we noticed that only 50ft of wire came with the solar panel kit. Our sponsor mentioned wanting to set up the solar panel on the roof. The school buildings they will be installing the power systems on will be one story buildings so we recommend that they ask the teachers or the school personnel in Liberia to measure the school room dimensions using a tape measure to estimate how much wire they will need. It can simply be done by finding a location within the room that would be protected from weather within the building, then taking a tape measure to measure how much wire they will need. This would help keep costs down and wire from being wasted.

5.6 Use the video tutorial and pamphlet to train teachers to set up and operate the Lab-in-a-Box

We recommend that HVK use the new video and pamphlet to train teachers and staff to set up and log into the system. The video and pamphlet will help teachers understand how the entire system works. It also will be useful in troubleshooting issues that may occur due to exposed wires or weather conditions.

6 CONCLUSION

The HVK Children's Foundation strongly believes that education is an invaluable key to a better tomorrow and created the Lab-in-a-Box to provide access to high-quality education for young students in impoverished, electricity-deficient rural areas of Liberia. We envision our ideal Lab-in-a-Box system will run smoothly for years to come. Updating both software and hardware components of the system will resolve its outdated-technology limitations while allowing more space and capabilities for the Lab-in-a-Box in the future. Our ideal Lab-in-a-Box will run Kolibri software on a Raspberry Pi connected to a high-storage-capacity device that will provide sufficient space not only to store more information for students and teachers but also to facilitate regular future updates. Our training programs will help teachers and staff onsite to be more confident in setting up and operating the Lab-in-a-Box. Because of this project, we understand more that we in developed countries sometimes take our virtually unlimited access to technology and education for granted. We have learned to appreciate what we currently have and give it back to those who can benefit greatly.

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