GO-GA: class experiences with Inquiry Learning Spaces in Go-Lab

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Abstract
The GO-GA project[1] was initiated to improve Science, Technology, Engineering and Mathematics (STEM) education in Kenya, Nigeria and the Republic of Benin. The rationale is to implement contextually engaging digital STEM education in Africa through the Go-Lab ecosystem. First the digital platform was adapted to meet teachers' needs, such as the option to change the language (French, Swahili). Then teachers were familiarized with Inquiry Based Learning (IBL), and trained to develop an Inquiry Learning Space (ILS), a personalized learning environment for students, on the Go-Lab ecosystem. Teachers subsequently implemented this ILS in class.
This study reports a pilot in which 55 teachers implemented ILSs in 44 schools, involving 1600 students. The overall research question was how ILS class implementation went. Online questionnaires for teachers and students were used to capture implementation. Two major challenges were anticipated: a pedagogical challenge, as the IBL methodology was new to the teachers and the students, and a technical challenge as class use presupposes sufficient computers and a stable internet.
Our results do show technological challenges: slow internet, a limited number of devices (computers, laptops), and students with limited computer knowledge. The pedagogical challenges were less pronounced than expected: most teachers reported to understand IBL, and most students indicated that collaboration in the group went well. Almost 90% of the teachers were satisfied, and more than 90% of the students were satisfied and enjoyed the lesson.
As a result of this study, recommendations for teacher training and for teacher support were made. However, the most important recommendation was to develop an app that facilitates **offline** use of an ILS. Schools would then no longer need an internet connection for students to work on an ILS.

Keywords: STEM education; digital learning environment; Go-Lab; Inquiry Learning

Introduction

Science and technology is becoming increasingly important in our society. To learn about science and technology is therefore essential for today's students. At a student personal level, this helps them to participate as informed members in society, and the scientific ways of thinking and scientific skills help them in making personal decisions based on evidence. At

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societal level it will help to cater for sufficient, well-educated practitioners in these areas. Hence there is a compelling need for appropriate Science, Technology, Engineering, and Mathematics (STEM) education, also at secondary school level (Bybee, 2013; De Meester et al., 2020).

In order to stimulate deep conceptual learning, Inquiry Based Learning (IBL) in which students engage in the scientific process, is often used in STEM education (National Academies of Sciences, and Medicine, 2019). The introduction of IBL in Africa faces a number of challenges. The lack of laboratories and science equipment in schools, and insufficient trained teachers to use IBL, are two of the main barriers. One possible way to overcome the first barrier is to replace (part of) the hands-on labs by virtual ones in a digital environment.

So the aim of this study is to establish whether it is possible to educate teachers to use IBL in class, train them to develop an ILS in the Go-Lab ecosystem, and evaluate class use of the ILS. This paper recounts the outcomes of class implementation of digital labs and simulations in the GO-Lab ecosystem in secondary schools in three African countries: Kenya, Nigeria and the Republic of Benin. Class practice, student and teacher satisfaction, as well as pedagogical and technical issues will be reported.

Conceptual framework

Inquiry Based Leaning (IBL)

Inquiry Based Learning (IBL) is a specific form of engaged or active learning (de Jong, 2019; Pedaste et al., 2015). In engaged learning students perform meaningful activities with the content offered, and go beyond the information that is offered to them (Freeman et al., 2014). In IBL, students are presented a scientific question and by performing investigations or collecting data, they are going to find an answer to this question. Based on the results of the investigations, students infer what this means for the subject domain (Xenofontos, Hovardas, Zacharia, & de Jong, 2020). In traditional teaching students often confirm knowledge, in IBL students construct meaning. IBL proved not effective when the entire process was left to the students (de Jong, 2019); students needed to be given the appropriate level of control (Lazonder & Harmsen, 2016). Finding the right balance between student and teacher (system) control is not simple (Bevins & Price, 2016) as this balance depends heavily on the educational culture (National Academies of Sciences, Medicine, 2018): what are students used to, what competences do the students have, and what expertise do the teachers have. Analysis of the PISA data has shown that the more open forms of IBL led to a more positive attitude towards science, and an increased interest and enjoyment in science. The more closed teacher-led forms of IBL led to higher knowledge scores (Cairns & Areepattamannil, 2019). The authors of the last study call for addressing each of the different domains (conceptual, epistemic, social, and procedural), and to allow for an appropriate level of guidance of students (see also the work of Kirschner, Sweller, & Clark (2006) explaining why minimal guidance does not work).

Lab work, virtual labs and Go-Lab

Lab work is quite common in the natural sciences. Furtak and Penuel (2019) argue that students “should engage in scientific inquiry, but with the priority of embedding those experiences in iterative cycles that will lead to the explanation of phenomena “. Osborne (2019) emphasises the “minds on” aspect, and stresses argue and critique activities as indispensable for scientists and engineers.

There is vast evidence that student learning outcome using non-traditional laboratories (virtual and remote) is at least equal to those using traditional labs (hands-on) (Dalgarno, Bishop, Adlong, & Bedgood, 2009; Gambari, Obielodan, & Kawu, 2017; Rowe, Koban, Davidoff, & Thompson, 2018; Rutten, van Joolingen, & van der Veen, 2012). Brinson (2015) carried out a comprehensive review of empirical studies comparing learning outcome achievement using traditional hands-on labs and non-traditional virtual and remote labs, and found that student achievement across all outcome categories (Brinson distinguished: knowledge and understanding, inquiry skills, practical skills, perception, analytical skills, and social and scientific communication) is equal to or higher in non-traditional labs.

Virtual labs have a number of advantages over hands-on labs: they are cheaper as no labs or equipment is required, have less environmental impact (no waste), students have unlimited access and can easily repeat experiments.

Combining virtual and remote labs with IBL has resulted in the Go-Lab ecosystem (www.golabz.eu). Digital labs from different repositories (such as the PhET labs, Amrita, Molecular Workbench, ChemCollective) have been brought together on this platform. However, this platform is not just a collection of labs, but it also houses a collection of apps and so called Inquiry Learning Spaces (ILSs) developed by teachers. An app is a small software tool that can help students in their inquiry process, such as a 'Hypothesis Scratchpad' to assist students to formulate a hypothesis, or a 'Table Tool' to assist in organizing experimental data (https://www.golabz.eu/apps). An ILS is a personalized learning environment for students, including a lab, apps, and other multimedia material (such as videos, images, external links, and articles). An ILS follows an inquiry cycle. The default Go-Lab inquiry cycle comprises of the following phases: orientation, conceptualization, investigation, conclusion, and discussion (Pedaste et al., 2015). In Kenya the 5E phases are used: engage, explore, explain, elaborate, evaluate. These phases are in line with the teaching approach adopted in Kenya. Teachers can configure the inquiry cycle they want to use to their own needs in Go-Lab. ILSs are developed and peer-reviewed by teachers. They know their students' needs and interests, and understand the educational culture at school. When developing an ILS, teachers can start from scratch with an empty ILS, from a lab from the Go-Lab lab repository, or they can copy an existing ILS from another teacher and modify this before using it with their students.

The teachers

Introducing Go-Lab in STEM education will affect the role of students and teachers in class. Teachers no longer transmit knowledge but engage students actively in learning science and mathematics. This requires teacher preparation before (van Uum, Peeters, & Verhoeff, 2019), and support during class implementation. To be successful, teachers need to acquire specific pedagogical content knowledge (PCK) (Shulman, 1986), which can be seen as an amalgam of content knowledge, pedagogical knowledge, knowledge of the curriculum, knowledge of the students, and knowledge of assessment practices (Gess-Newsome, 2015). To describe the way teachers integrate ICT skills into their teaching, Technological Pedagogical Content Knowledge (TPCK) has been introduced (Koehler & Mishra, 2013). A study conducted in Tanzania in 2018 by Mtebe & Raphael (2018) shows that teachers confidence level in TPCK is lower than that in Content Knowledge and Pedagogical Knowledge. Integrating ICT by teachers into their teaching pedagogies is not easy (Mwangi & Khatete, 2017).

The teachers involved in GO-GA need to learn what Inquiry Based Learning (IBL) is, how this relates to doing lab work, and the pedagogies that can be used to actually teach in the IBL spirit. And on top this, teachers also need to become familiar with the Go-Lab digital ecosystem (de Jong, Sotiriou, & Gillet, 2014) in order to develop the ILSs they are going to use with their students. Successful class implementation further requires a proper digital infrastructure at school: sufficient computers or laptops for class use. As teachers in class use routine actions, changing these is complicated (Schön, 1983) and teachers will first need to unlearn their previous "repertoire". So, it is not surprising that even after teacher preparation, there might be some hesitation from the side of the teachers to bring their newly developed knowledge and skills into the actual classroom practice. Preparing teachers is therefore seen as a process, not just an event (Fullan, 2007), it takes time. Different models have been developed to visualize such complex teacher learning (Clarke & Hollingsworth, 2002; Coenders & Terlouw, 2015), and these models also apply to learning how to deal with inquiry learning in a digital environment.

Context of the study

This paper reports the findings of a pilot in which teachers in Kenya, Nigeria and the Republic of Benin, implemented an inquiry learning space (ILS) using the Go-Lab platform in their classes. Teachers participated voluntarily. Only teachers who had internet at school where invited to join this pilot. Before class implementation the teachers received training: first a three day introductory course in IBL, and then a three day course about developing an ILS using the Go-Lab ecosystem. Most teachers implemented the ILS they had developed themselves in class at their school. Some however used an ILS developed by a colleague. During implementation, teachers were supported through a Teacher Implementation Manual (TIM), an online help-desk (chat), e-mail, and a WhatsApp group in which teachers and support staff could easily communicate. The concise 37 pages TIM consisted of six chapters, partly giving practical "how to" advice and partly background information about IBL and suitable pedagogies for IBL.

In this pilot, technical and pedagogical challenges were anticipated. The technical challenges were related to the schools' infrastructure, such as the availability of computers and of a proper internet connection. The pedagogical challenges incorporated how the teachers implement the ILS in class, and how students react to it. The following research questions guided this study:

1. How does ILS class use in each of the three pilot countries look like?
2. How do teachers assess their preparedness for and satisfaction about class use?
3. How do students assess their learning and satisfaction about working on an ILS?
4. What pedagogical and what technical issues emerged during class use?

Research method

Participants and design. In this pilot 55 teachers from 44 different schools taught 61 ILS classes. In each country (Kenya, Nigeria, the Republic of Benin) the pilot started with an official launch. The objective of this research was to capture class use, so we did not utilize a quasi-experimental design but evaluated what happened in each class (Corbin & Strauss, 2008).

Instruments. Online questionnaires were used to capture what had happened, and how students and teachers perceived this new way of teaching and learning. The student questionnaire consisted of 10 open and 13 closed questions. Most student questionnaires were completed by the group of students who had collaborated on the ILS. As the number of questions for the teachers was rather high, it was decided to divide these over two separate online forms: one with factual questions, having one open and 17 closed questions, and one for teachers' experiences, seven open and 16 closed questions.

Analysis. A total of 55 teacher questionnaires, and 398 student-group questionnaires were analyzed. The answers were clustered to match the research questions. In order to make sense of the open questions, grounded theory principles were used (Corbin & Strauss, 2008; Gibbs, 2018): we did not define categories beforehand, but these emerged when reading the different answers.

Results

For each of the research questions the results will be presented below.

1. How does ILS class use in each of the three pilot countries look like?
   The following table shows the most prominent results for class use. All data were reported by the teachers, by the students, or by both.

	Kenya	Nigeria	Benin
Number of teachers	23	15	17
Number of female students	459	211	175
Number of male students	383	108	265
Number of students per device (computer or laptop)	1-4: 43,4% 5-6: 26% > 6: 17,4% whole class: 4,3%	1-4: 95% 5-6: - > 6: 5% whole class: 0%	1-4: 29,5% 5-6: 47,0% > 6: 17,6% whole class: 5,9%
Improvement suggestions from students	Stronger internet More computers More time More videos, images, notes in ILS	Stronger internet More computers More videos, images	We received very few suggestions, some: stronger internet no English

The Table shows remarkable differences between the countries. Especially when it comes to the available number if devices it is clear that in Nigeria schools are quite well equipped, but on the other hand Benin needs to invest in devices.
Almost all respondents suggest to invest in stronger and faster internet.

2. How do teachers assess their preparedness for and satisfaction about class use?
   All data in the table below were reported by the teachers.

	Kenya	Nigeria	Benin
Teacher satisfaction	81,8% satisfied	89,5% satisfied	93,3% satisfied
How prepared for class use did the teacher feel?	Well: 86,4% Neutral: 9,1% Not well: 4,5%	Well: 79,4% Neutral: 15,3% Not well: 5,3%	Well: 93,3% Neutral: 6,7% Not well: -
ILS development? - from scratch - with a colleague - copied and modified - used existing one	 : 65,2% : 26,1% : 8,7% : -	 : 50% : - : 20% : 30%	 : 52,9% : 5,9% : 5,9% : 35,3%
Did the teacher understand the Inquiry Learning methodology?	Well: 91,0% Neutral: 4,5% Not well: 4,5%	Well: 84,2% Neutral: 5,3% Not well: 10,5%	Well: 93,3% Neutral: 6,7% Not well: -

We also asked the teachers what support structures they had used during the pilot. Available were the Teacher Implementation Manual (TIM), WhatsApp group, e-mail, and online chat. Most teachers mentioned to having used only one of these, and not even often. The TIM was used most in each of the countries, followed by the WhatsApp group and then the online chat. The TIM was distributed as a paper version, so even without an internet connected teachers could consult it. The WhatsApp app ran on the teachers' private mobile phones.

3. How do students assess their learning and satisfaction about working on an ILS?
   Most of the questions about student learning and satisfaction were posed to both the students as well as to the teachers. As the answers do not always align, in the following table the answers from both groups will be shown. For example, on the first question about how satisfied the students were with the lesson, the students answered and also the teachers responded how they assessed student satisfaction.

	Kenya	Nigeria	Benin
Student satisfaction (student replies) (and according to the teacher)	95,3% satisfied 96 % satisfied	96.9% satisfied 99,9% satisfied	88,9% satisfied 100% satisfied
Home internet use for study (student replies) (and according to the teacher)	Often: 32,9% Sometimes: 47,7% Not: 19,4% Use it: 30,4% Not use it: 43,5% Unknown: 26,1%	Often: 49% Sometimes: 37,7% Not: 13,3% Use it:75% Not use it: 10% Unknown: 15%	Often: 22,2% Sometimes: 46,3% Not: 31,5% Use it: 5,9% Not use it: 35,3% Unknown: 58,8%
Computer knowledge (student replies) (and according to the teacher)	Enough:84% Insufficient: 16% Enough: 27,3% Insufficient: 72,7%	Enough: 83,7% Insufficient: 16,3% Enough: 42,1% Insufficient: 57,9%	Enough: 55,6% Insufficient: 44,4% Enough: 20% Insufficient: 80%
Mostly liked in class (students)	The lab: 24% The video: 21% Other answers: 55%	The lab: 35% The video: 24% Other answers: 41%	The lab: 39% Learning content: 19% Other answers: 42%

Overall it is clear that both teachers as their students were quite satisfied about the ILS lesson.
We noticed a larger discrepancy between student and teacher answers when it comes to having sufficient computer knowledge, the students rated this much higher than their teachers.
The students were also asked to indicate what they had learned in this lesson. This resulted in a large number of student answers. These could be categorized as (between brackets the average percentages of the three countries):

- Specific content matter (62%)
- Easier to understand (19%)
- Computer/internet use (17%)
- Interesting to learn and more efficient (7%)

- Other (4%)

Some examples of student on the question “what did you learn from this lesson?” are:

- Effects of temperature and light on the state of photosynthesis.
- It’s easier to understand the concepts.
- That computers are the best learning gadgets and should be open to all students to familiarize themselves with it.
- It is interesting and makes work easier since the teacher does not have to write on the board thus the student understands.
- I learned to experiment.

4. What pedagogical and technical issues emerged during class use?

Pedagogical issues

The focus here was on what happened in class: what did the teachers do when the students worked the ILS and how was the student collaboration. The last question was posed to both the students as the teacher.

	Kenya	Nigeria	Benin
What did the teacher do in class?			
- monitor groups:	37%	19%	25%
- answer group questions:	30%	26%	25%
- explain procedure to whole class:	23%	37%	27%
- explain content to whole class:	7%	15%	23%
- other:	3%	3%	0
How was student collaboration?			
(student replies)			
- well:	90,0%	92,9%	88,9%
- neutral:	5,9%	3,1%	7,4%
- not well:	4,1%	4,0%	3,7%
(and according to the teacher)			
- well:	77,1%	84,2%	80,0%
- neutral:	9,3%	5,3%	6,7%
- not well:	13,6%	10,5%	13,3%

Here we noticed that students rate their collaboration higher than their teachers.

In this category we also asked for ‘normal class’ practice with respect to doing assignments and doing practical work in the school science laboratories. Doing assignments for the STEM subject seems common, in all countries 90% of the students said to have at least regular assignments to do. Practical work varied: in Kenya 95% of the students said to have at least regular practical work, in Benin this is 60%, and in Nigeria 90%. So working on assignments is rather normal for students, they should therefore not have problems working on the assignments in the ILS. Most students also have experience with practical work, though less in Benin, so the use of the lab in the ILS is not an unfamiliar activity.

Technical issues

When a digital platform is used, that requires an internet connection, technical issues are expected. We were interested about the devices that could be used, how the internet connection is perceived, and what technical problems might have popped up. The following table shows a summary of the results. All data are from the teachers.

	Kenya	Nigeria	Benin
What devices were used? - Desktop computers - Laptops - Tablets - Smartphones	 35,2% 47,8% 6,5% 10,5%	 25% 50% 12,5% 12,5%	 6,3% 84,2% none 9,5%
How is the internet connection perceived? Pages loaded: - Quickly - Well - Neutral - Slow - Very slow	 none 26,1% 34,8% 34,7% 4,4%	 25% 15% 35% 5% 20%	 41,2% 35,3% none 11,7% 11,8%
How many teachers experienced technical problems? What problems?	54,5% Slow internet	74,7% Slow internet	66,7 % Slow internet Power supply

It is clear from these data that the number of devices varied across the countries, and that slow internet is one of the major technical challenges.
One advantage of using a digital environment on the internet is that all student answers are automatically recorded and can be assessed. In order to get an impression of student answers we copied and examined the work of four randomly chosen student groups in four ILSs. We noticed:

- That student groups were able to work on an ILS successfully.
- That time constraints was a serious factor for not finishing in one class period. Slow internet might be the reason for this.
- That some assignments or exercises were skipped (no answers were given at all). We do not know whether this was because of time constraints or because the students could did not have an answer.
- That it is not possible to conclude what students exactly had learned, as we did not assess their initial knowledge. But we could see that all groups had performed an experiment and recorded experimental data.

Conclusion

Go-Lab can be successfully used for STEM education in Kenya, Nigeria and the Republic of Benin. The results from 55 teachers who have used an ILS in their classes, and their 1601 students (845 female and 756 male) evidently show this.
The number of available devices (desktops, laptops) in schools needs to increase when we want students to collaborate effectively. Ideally would be two or three students per computer. Up to four students per device is workable, and this target is almost reached in Nigeria (95%), but neither in Kenya (43%) nor in Benin (30%). This low number of devices in combination with the experienced slow internet makes it understandable that many students and teachers recommend investing in computers and in a faster internet connection.
Teachers were in general quite satisfied with the ILS lesson. Teachers also felt well enough prepared for class implementation. Quite a number of teachers used an ILS developed by or

with a colleague. Teachers indicated to understand the IBL methodology well. This means that the teacher preparation programs have been successful.
Students were also satisfied and happy about this ILS lesson, and this was confirmed by their teachers. Students do use internet at home for school purposes, but the percentages are still rather low, less than 50% of the students use internet often. Computer knowledge is rated high by students themselves, but teachers differ in this respect. There might be a need to teach specific computer skills before ILS use. That students liked the lab most in the ILS is encouraging, as this means that they like doing experiments.
The fact that quite a few teachers had to explain content to the whole class is remarkable. This could mean that there is a discrepancy between initial students' knowledge and what teachers assumed this knowledge to be when the teachers developed the ILS for class use. It is interesting to see that 90% of the students responded that their collaboration went well, teachers however rated this about 10% lower.

Recommendations

Our conclusions resulted in a number of recommendations for the next pilot. As slow internet is a big issues, an *offline* option will be developed so that at school no internet connection is required. Teachers develop the ILS *online*, subsequently download this ILS in the application for *offline* use, and then use it with their students in class *offline*.
Most of the recommendations resulting from this pilot were geared to strengthen teacher training. One of these is to use the Teacher Implementation Manual throughout the training so that teachers know where to find what kind of information. Others are about specific elements in an ILS, such as: because the lab is at the heart of an ILS, write clear and concise student instructions for manipulating the lab, and for data recording; do not use long explanatory texts; avoid long introductory videos; take the prerequisite knowledge into account. And maybe most important: have the students reflect on the content and on the process. This can be done in the lesson immediately following the ILS lesson.

Discussion

It is important to bear in mind that the presented data were self-reported by the teachers and the students. We did not do class observations nor a pre- or post-knowledge test. Another important aspect is that only teachers who had internet at school could participate. It is most likely that these schools also have a larger number of computers than schools without internet. Our next pilot, where teachers can use the *offline* functionality, will show what the situation is in schools where internet is not available.
However, we have noticed that even with only *one* working computer plus a projector, an ILS lesson can be very effective, that is also an outcome of this pilot.

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