

Enhanced STEM Learning with Online Labs:

Empirical study comparing physical labs, tablets and desktops

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Abstract- India's educational challenge includes a large school going population, shortage of science teachers and lack of science labs in many schools. To counter this challenge, the Online Labs (OLabs) pedagogy is designed as a complete learning environment with tutorials, theory, procedure, animations, videos and simulations while the assessment includes conceptual, experimental, procedural and reporting skills.

We discuss two separate empirical studies using OLabs to study the performance gains, student attitudes and preferences while using physical labs, desktops and tablets. The first study was at a school that compared students who learnt individually with OLabs on desktops, to students who learnt with the traditional teacher led physical labs. The second study was at a science camp and compared OLabs on desktops to OLabs that were context adapted for android tablets. There were significant differences between the physical labs and the self study mode using OLabs on desktops, but no significant differences between OLabs on desktops compared to OLabs on tablets.

Keywords—Olabs; traditional labs; animation; simulation; online labs; virtual labs; elearning; cognitive learning; conceptual skills; experimental skills; procedural skills; reporting skills; assessment

I. INTRODUCTION

The National Focus Group on “Teaching of Science” suggests prevention of marginalization of experiments in the school science curriculum. In this regard, investment is required for improving school labs to promote an experimental culture. Majority of the schools in developing countries, lack both minimum infrastructure and trained teachers. Often assessment of practical skills for a large class size is difficult and may comprise of well written assignments or objective assessments alone.

OLabs science simulations are based on sophisticated mathematical models that offer a complete learning environment of science practical labs with interactive tutorial animations, video demonstrations and assessments. OLabs was recommended by the Central Board of Secondary Education (CBSE) as a teaching and learning aid to the 15000 schools that follow the CBSE curriculum.

We discuss two separate empirical studies using OLabs to study its effectiveness, performance gains and student attitudes and preferences using different modalities and compare it to traditional labs. The first study was at a school that compared students who learnt individually using OLabs to perform the experiments on the computer lab, to students we did the experiments at the teacher led traditional labs.

The second study was at a science camp and compared students learning with OLabs on desktop computers v.s. OLabs that were context adapted for low cost android tablets. There were significant differences in learning and performance between the teacher led traditional labs and the self study mode using OLabs on desktops, but no significant differences between OLabs on desktop computers compared to OLabs on tablets.

II. SIMULATION FOR PRACTICAL SCIENCE EXPERIMENTS - A SURVEY

Many educators suggest that computer simulations offer considerable potential for the enhancement of the teaching of science concepts. Simulations enable students to have direct control by modifying variables and being able to visualize the effects of their changes [1]. While both traditional laboratory activities and simulation are forms of inquiry which engage the learner in the process of observing, hypothesizing, experimenting and forming conclusions, computer-simulated experiments, as inquiry tools, are considered by some authors to be superior to conventional laboratories [2]. A model-based learning using simulations within a complete learning environment instead of stand-alone simulations was discussed in [3]. Some authors have proposed a framework for combining traditional and virtual labs based on specific learning outcomes such as cognitive, affective and psychomotor related objectives and concluded that student's conceptual understanding was enhanced by the combined learning approach [4], [5].

As students can immediately see the output to simulations based on the input they provide, they can make connections between the hypothesis and the results [2]. A framework for learning-enabled online assessment of practical skills, which gives due consideration to both the structure of the practical assignments and immediate feedback promotes learning [6]. Simulations teach both real and theoretical behavior to the learner [7]. Reference [8] through their interactive science simulations allowed students to explore science topics and concluded that with minimal explicit guidance students were able to perform in ways similar to how scientists explore phenomena. Immediate responses may encourage students to examine various system states without fear of making mistakes or being criticized. Control of variables enable students to assess the effect of each individual variable as well as their combined effects, promoting clearer understanding of this key aspect of inquiry work. OLabs provides a flexible simulation environment, which maps to the school curriculum while allowing additional variables that can be controlled by the student to enable a richer learning experience.

Simulations engage the learner, provide visualization and show the effects and consequences [9]. Some studies suggest that simulations used in science education can be classified along four dimensions: the amount of user control, the extent and nature of the guiding framework of how information is represented, and the nature of what is being modeled [10]. OLABs consist of rich interactive simulations based on accurate mathematical models, tutorial animations and video demonstrations, feedback and scaffolds, and the assessment of various skills. Simulations offer a learner direct experience of a system, even though it is simulated [11].

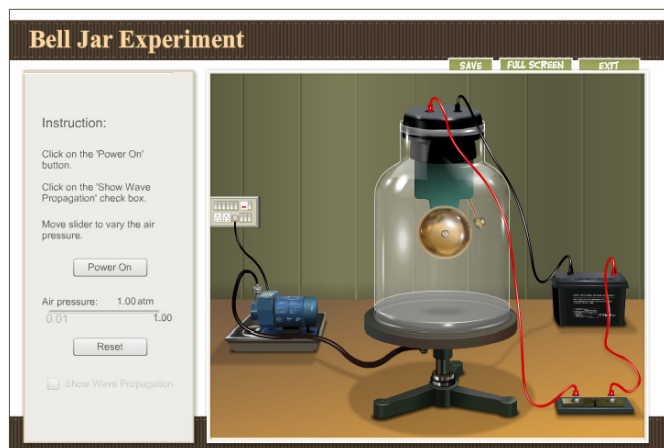


Fig. 1. Simulation of the Bell Jar experiment.

The OLABs simulation labs allow a student to experiment with dimensions that are impractical or impossible in a lab, e.g. performing experiments in a zero gravity environment. It eliminates time-consuming setup and allows learning of experiments that require equipment that is too expensive to purchase. The complete set of supporting materials such as the theory, lecture notes, animation and video tutorials are in an organized form as related to the experiments being performed and has supplementary reading on the related material. The simulations and assessments have automated feedback and scaffolds to aid in better learning outcomes. Assessment of lab skills includes conceptual knowledge, procedural and manipulative skills, understanding the experiment and the equipment including manipulating them and reporting and interpreting skills.

III. THE OLABS DIFFERENCE - MULTI-PRONGED LEARNING ENVIRONMENT AND ASSESSMENT

There is universal acceptance of the importance of performing experiments in the school physical lab to enhance students' conceptual understanding in science. When there is limited time to access physical science labs, the learning cycle is limited as learners cannot try out different scenarios [12]. In addition, a formal assessment of science lab skills is lacking, with most schools employing the traditional theory based or multiple choice questions (MCQs) to evaluate students.

Simulations are not a total learning package but provide only a part of the learning experience but must be integrated into a curriculum, which provides support for the simulation and in which the simulation supports other learning activities

[13]. OLABs is built not just as stand-alone simulations but as a complete learning environment with supporting theory, animations, videos, tutorials, interactive simulations, assessments and reference material.

Simulation based labs for science experiments have been an increasingly growing trend to alleviate this problem but they provide only a part of the lab experience. What is needed is an integrated approach for assessment-for-learning of simulation based lab skills. Such an approach will have the following four quadrants –a) simulation based labs (Fig. 1) b) feedback and scaffolding c) assessment of lab skills (Fig. 2) d) animations (Fig. 3) and video tutorials in an organized form as it relates to the experiments being performed and supplementary reading on the related material.

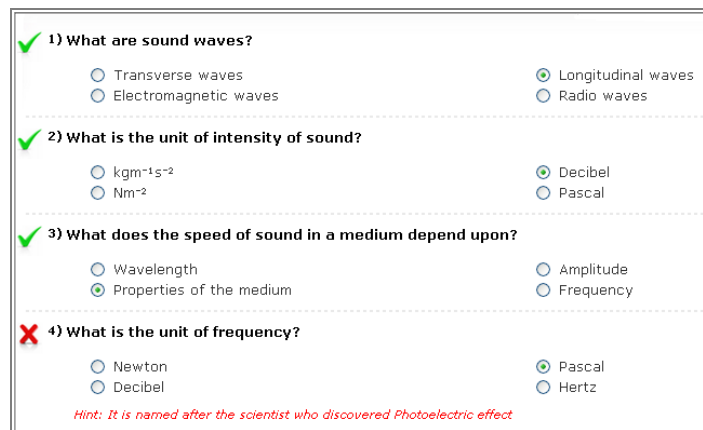


Fig. 2. Assessment – Multiple Choice Type.

Assessment of practical skills in science in an objective manner is a difficult task with the difficulty increasing manifold if the assessment is to be carried out when a class size is large. The Central Board of Secondary Education (CBSE), India mandates that conceptual skills, procedural skills, experimental skills and reporting skills are improved and assessed as part of science labs and hence our study incorporates all four skills.

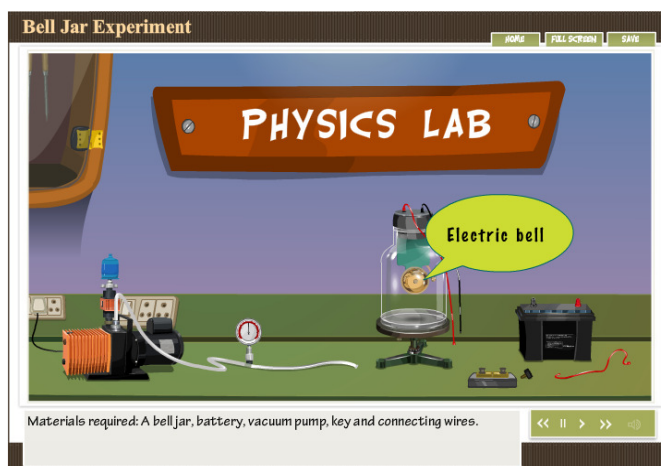


Fig. 3. Animation of the Bell Jar experiment.

IV. Collaborative Accessibility Platform for Practical Skills

OLabs are hosted on a distributed Collaborative Assessment Platform for Practical Skills (CAPPS) [14]. CAPPS reduces the cost of deployment of labs by scheduling and allowing secure access of online labs. In addition to this, CAPPS has a collaborative authoring module to create new labs and a built-in learning management system. The iLabs developed at the Massachusetts Institute of Technology [15] that provides this kind of architecture for developing and deploying labs built by multiple institutions. CAAPS provides a single user interface to labs developed by multiple institutions, thus allowing the student to access any available lab that are built by different authors and geographically distributed at different institutions.

V. RESEARCH STUDY

A. Research Questions

1. How do traditional lab learning with teacher instruction and OLabs without teacher intervention but tutorial e-learning material compare when evaluated by the four types of assessments such as conceptual, procedural, reporting and experimental skills?
2. On evaluating the four assessment types, are OLabs with content and context adapted for tablets comparable to OLabs on desktops?

B. Participants and Materials

There were two separate studies conducted using OLabs. The first study comparing traditional labs with OLabs at the computer lab was conducted in a school in Kerala, India in with (n=59) eleventh grade students. The second study comparing OLabs on tablets with OLabs on desktop was done during the DST Inspire Science Camp in May 2012 with (n=62) eleventh grade students.

Android tablets and Desktops were connected to the OLabs server. Traditional Labs had the physical equipment to perform the experiments.

C. Measures

A 5 point Likert-scaled questionnaire to gauge student perceptions of the ease-of-use and preferences for OLabs and for device types was conducted after the post-assessment.

The CAPPS tracks every input of the student, including the current state of the experiment, variables changed by the student, pages visited and time spent on each page, thus providing a complete history of all student activity. The number of questions attempted and the answer choices selected are logged. These have been used in the analysis.

D. Case 1 Traditional Labs v.s. OLabs

The students were randomly divided into two groups using the cluster sampling method of numbers for the experimental groups, one using OLabs and the other control group using the traditional labs. The students were given a brief introduction about the study and then given the pre lab assessment to check their knowledge level of the given experiment at that stage. In the computer lab: they were instructed to go through the theory

first, followed by the procedure, tutorial video/animation, the simulation and then the viva questions. The traditional lab was conducted exactly as it is typically done in the school, with a subject matter expert from our team explained and demonstrated how to perform the complete experiment after which the students performed the experiment.

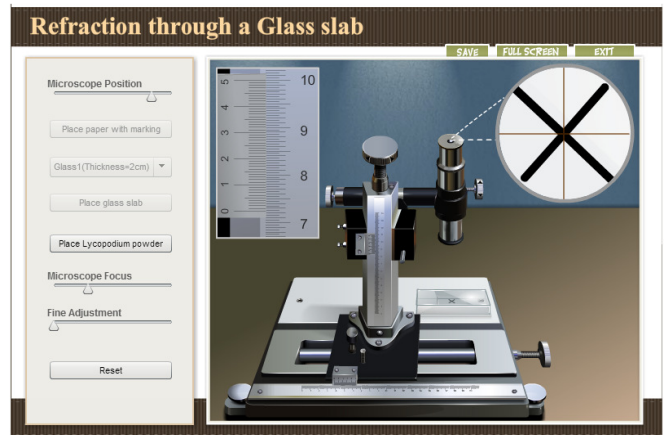


Fig. 4. Simulation of experiment 'Refractive Index of a Glass Slab'.

The students from both the groups performed the experiments and then completed the lab records using the template provided. Then the students were given the post lab questionnaire. Finally they answered a post lab survey. The experiment selected for this study was, "Refractive Index of a Glass Slab" and the objective of the lab is to determine the refractive index of a glass slab (Fig. 4).

E. Case 2 OLabs on Desktops v.s. Tablets

The experiment selected for this study was the 'Verification of Archimedes' Principle' (Fig. 5) and the objective of the lab is to establish the relationship between the loss in weight of a solid and weight of water displaced when the solid is fully immersed in various solutions.

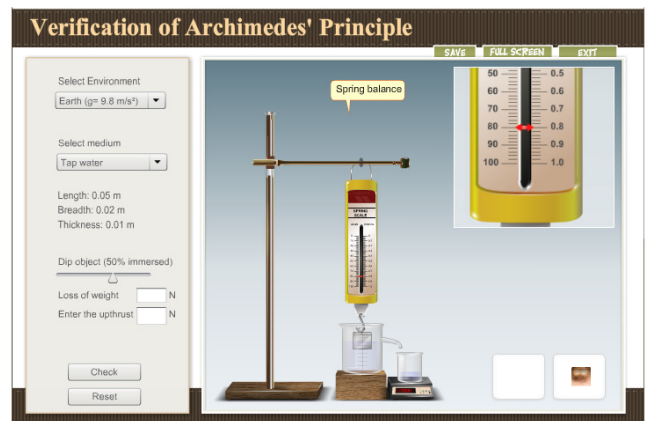


Fig. 5. Simulation of experiment 'Verification of Archimedes Principle'.

Students were randomly divided into two groups for the tablet and the desktop studies and were assessed using the same pre-test and post-test. They were asked to go through the learning materials such as the theory, procedure, video, animation tutorials and then perform the experiment after which they needed to answer a Likert scale questionnaire. The

learning material was similar for the tablets and desktop though it was context and content adapted for tablets.

VI. DISCUSSION

This study suggests that an integrated OLabs environment which included learning tutorials relevant to the simulation has the potential to increase STEM learning. When compared to traditional labs with teacher demonstration, OLabs had an advantage in conceptual skills, while traditional labs had an advantage in procedural and reporting skills.

OLabs was equally effective on both desktop computers and on android tablets though the context and content of OLabs was adapted to fit the smaller screen sized lower powered android tablets.

A. Case 1 Traditional Labs v.s. OLabs

In both groups, the performance improvement between the pre-test and post-test scores could be significantly noticed using paired t-test. After adjusting for pre-test scores, there were significant effects of the two between-subjects-factors: Instruction type, $F(1, 48) = 4.51, p < .05$, partial $\eta^2 = .086$; and Gender, $F(1, 48) = 14.87, p < .005$, partial $\eta^2 = .237$. Adjusted mean post-test scores suggest an advantage to traditional laboratory instruction ($M=13.28, SE=0.34$) over OLabs, ($M=12.4, SE=0.33$); as well as an advantage to Males ($M=13.76, SE=0.31$) over Females ($M=11.91, SE=0.37$). The interaction between instruction type and gender were insignificant.

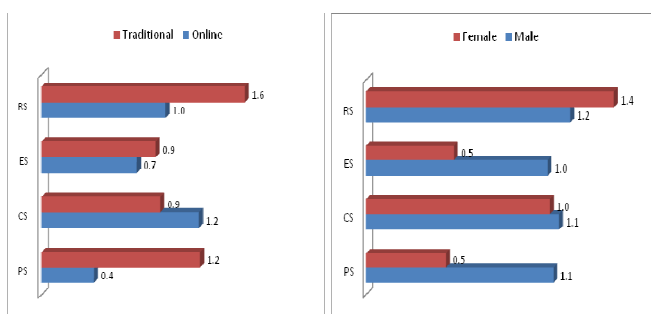


Fig. 6. Mean Improvement in Score (posttest-pretest) based on type of Lab and on Gender.

As all the students in the OLabs group worked with the simulation, the advantage seen in OLabs group over Traditional Labs in conceptual skills may be a direct result of performing the simulation.

Interestingly, analysis based on the four assessment types suggest an advantage to Traditional Laboratory for the Procedural and Reporting skills ($p < .05$), with no significant difference seen in Experimental skills ($p > .05$), and an advantage to OLabs in the Conceptual skills ($p < .05$).

A possible reason for the lower performance in the procedural skills of the OLabs group may be that the traditional group had the advantage of instruction and demonstration by the subject expert. Though the OLabs group was instructed to watch the tutorial video and animation, we noticed that many of the students skipped this and went on directly to perform the online simulations.

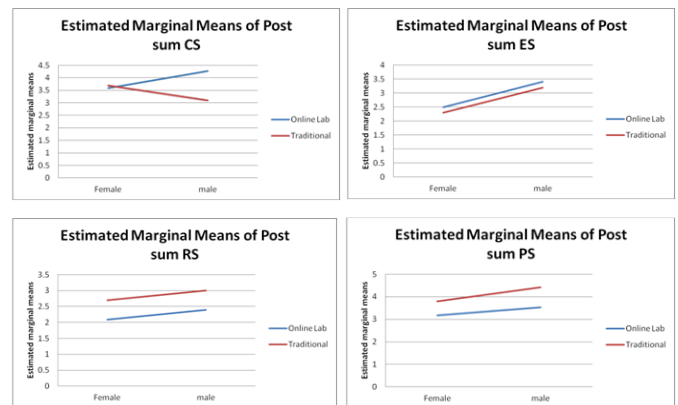


Fig. 7. Estimated Marginal Means of Post Sum Conceptual Skills (CS) Experimental Skills (ES), Reporting Skills (RS) and Procedural Skills (PS).

As all the students in the OLabs group worked with the simulation, the advantage seen in OLabs group over Traditional Labs in better conceptual skills could be a direct result of the learning environment integrated with the simulation.

TABLE I. SUMMARY TABLE FOR EACH CATEGORY BASED ON INSTRUCTION TYPE AND GENDER

Skill Type	Instruction Type Traditional v.s. Online Labs	Gender
PS	T>O	M>F
CS	T<O	M=F
ES	=	M>F
RS	T>O	M=F

There also seem to be an advantage to males over females in the overall performance for PS and ES skills.

Most studies of simulations have focused on conceptual understanding, providing promising evidence that simulations can advance this science learning goal. We have included four types of assessments required by the Central Board of Secondary Education, India and a complete learning environment that attempts to replicate teacher instruction.

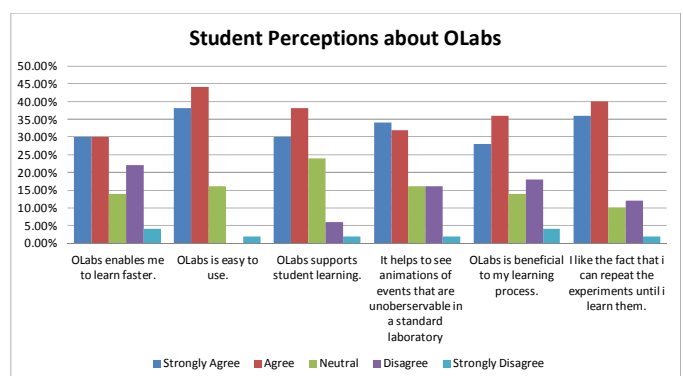


Fig. 8. Student Perceptions about OLabs.

It would be interesting to replicate this study so that students are mandated to go through the theory sections, the tutorial videos and animations before attempting the simulation.

B. Case 2 OLABs on Desktops v.s. Tablets

As the research study was held as a competition at a Science camp held at Amrita University and the students were motivated to perform well. Unlike in CASE 1, which was a mixed ability class from one school, the students selected to attend the camp were all high performers from different schools.

The students were randomly divided into two groups. Both groups were given the same instruction and performed the same experiment, the only difference being that the group with the tablets had content that was context and content adapted for the smaller screen.

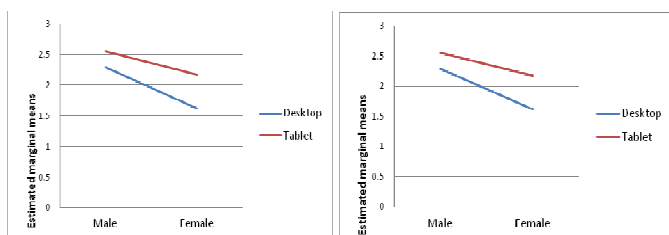


Fig. 9. Estimated Marginal Means of Post Sum Reporting Skills(RS) and Experimental Skills (ES).

A paired t-test showed that the total mean post_test (11.1167) score for both is significantly higher than mean pre_test(9.2333) score. The mean post_test (11.4) score is significantly higher than the mean pre_test(9.5) score for device tablet and the mean post_test (10.8333) score is significantly higher than the mean pre_test(8.966) score for device desktop ($p < .05$ in both cases). Hence both groups improved their performance after using OLABs.

For this OLABs experiment, there seems to be an advantage to males over females in the overall performance for ES and RS skills ($p < .05$ in both cases).

TABLE II. SUMMARY TABLE FOR EACH CATEGORY BASED ON INSTRUCTION DEVICE AND GENDER

Skill Type	Instruction Type (desktop or tablet)	Gender
PS	=	=
CS	=	=
ES	=	M>F
RS	=	M>F

However, there is no difference in test scores between Desktop and Tablet in post_test ($p > .05$) showing that in spite of context and content adaptation for the smaller screen size and the capacity of the android tablets, the learning outcomes are similar.

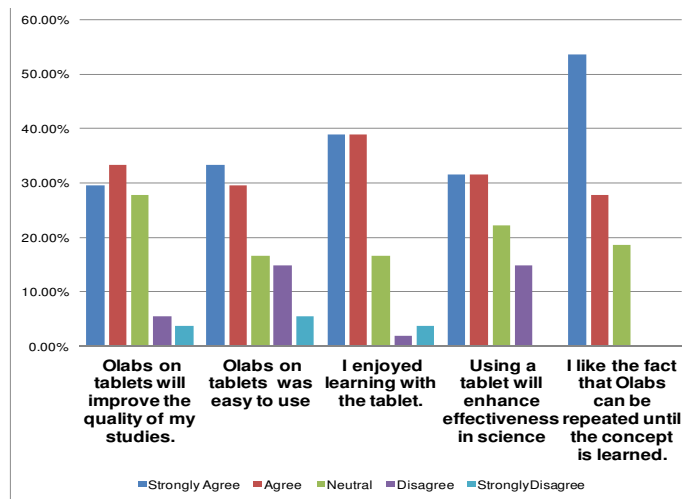


Fig. 10. Student Perceptions about OLABs on tablets.

VII. CONCLUSION AND NEXT STEPS

Science learning is a complex process and simulations built with supporting learning material have the potential to advance multiple science learning goals, including motivation to learn science, conceptual skills, procedural skills, experimental skills and reporting skills.

This study comparing pre and post test scores showed that that the integrated OLABs environment significantly increased STEM learning using both desktop and mobile devices in all skills.

When compared to traditional labs, students using OLABs had a significant performance improvement in conceptual skills than in traditional labs. While the simulation itself was developed to be similar to the traditional lab, OLABs had an integrated learning environment that includes video demonstration, animation, references and the conceptual theory behind the experiment was more useful than just performing the experiment after a tutor lead demonstration. OLABs could be repeated many times and 81.4% of the students liked the fact that they could repeat the experiments until they learnt the concept.

Overall the traditional lab students performed better in the reporting and experimental skills and a possible explanation could be that the traditional group had the advantage of a demonstration of the entire procedure of the experiment by the subject expert before performing the traditional lab. This was to done to maintain the current traditional labs in India, where the teacher demonstrated the experiment before the students attempt to work on it.

OLABs was equally effective using either desktop computers or android tablets even though OLABs was context and content adapted to fit the smaller screen size and lower processing power of the android tablets.

The assessment in the school showed an advantage over males to females in science practical skills for procedural and experimental skills whereas the assessment at the Inspire Science Camp showed an advantage to males over females for experimental and reporting skills. An interesting area of study

in the future would be to understand the cause of the lower performance in girl students and perhaps find ways to modify OLabs and traditional labs to overcome the gender differences in STEM learning.

VIII. ACKNOWLEDGEMENT

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