Chemistry on Computers in East Africa – Lesson Plans from Collaborative Exchange

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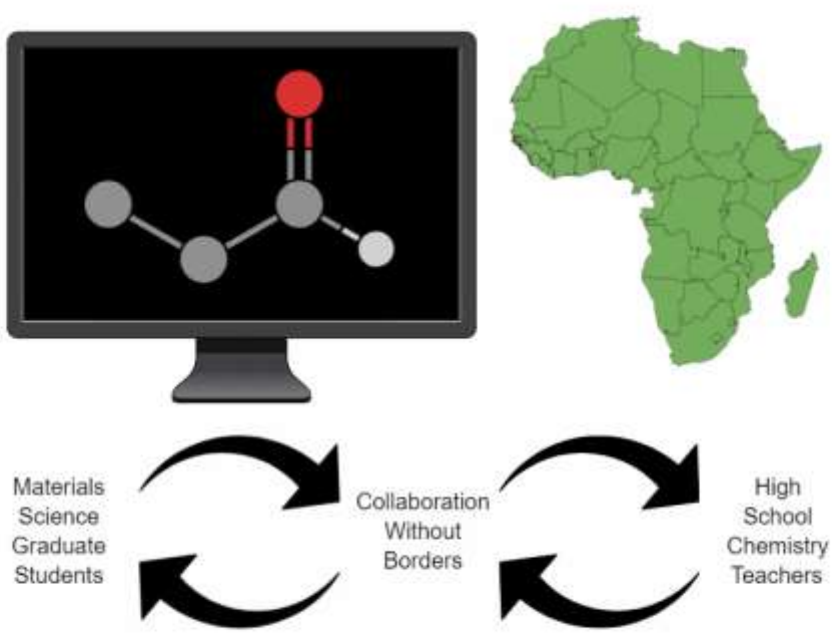
ABSTRACT

Meeting the challenge of modern global chemistry education requires collaborations from many different actors. Here, we report the development of computer-based lessons on VSEPR and Unit Cells designed specifically for implementation in the unique environment of East African high schools. The lesson plans use software more commonly employed by materials science graduate students, here repurposed for the high school chemistry classroom. The lesson plans were successfully piloted in local schools, indicating their potential for wide impact. The complete lesson plans are provided for free here as in the supplemental information section. The careful design of the lessons based on specific environmental factors through multi-faceted contributors suggests a model of collaboration that could be useful in many other contexts.

GRAPHICAL ABSTRACT



KEYWORDS

High School / Introductory Chemistry, Curriculum, Collaborative / Cooperative Learning, Computer-Based Learning, Multimedia-Based Learning VSEPR Theory, Inorganic Chemistry

INTRODUCTION

Although Africa (particularly sub-Saharan Africa) produces only a small fraction of the world's scientific research, the scientific publication output rate is growing faster in Africa than in any other world region.[1] There is an ongoing conversation on how to best guide the growth of African science,[2] but most agree that a foundational component of such development is the continuous improvement and modernization of science education, including chemistry education.[3] Of course it is not so easy as well-meaning external actors simply proposing innovations in chemistry education in Africa or for any other issue for that matter.[4] Context matters.

Teaching chemistry in difficult circumstances is a challenge.[5] Observers have debated what it means to decolonialize science education in African contexts, but it probably starts with lessons that take cognizance of the societies in which they are located.[6] Indeed, many agree that at least one aspect of the decolonialization process is anchoring the science curriculum in local experience.[7]

With that in mind, we take a moment to explore the local context for chemistry education in Africa with focus on local curricula and environment, in Kenya and Tanzania in particular. In Kenya, high school computer labs are nearly universal there and have been for some time, and traditionally they have been used for computer technology literacy purposes. Kenya has been particularly energetic in promoting technology in its public education system in recent years – beyond the long-standing high school computer labs, it has introduced initiatives to provide tablets to every elementary school student. And even without such official initiatives, Kenyan students are becoming more and more familiar with technology earlier and earlier in their lives, due to increasing globalization and increasing affluence in Kenya. As such, computer literacy classes in high school are becoming increasingly irrelevant and unnecessary. To repurpose high school computer labs, the solution proposed by education officials in Kenya is to start using the labs to teach science content – lessons in physics, chemistry, and biology, on computers. The responsibility for developing such new lessons has fallen rather unceremoniously on practicing high school science teachers, few of which have the time or resources to develop completely new lessons to be delivered on computers. This is the recent state of affairs according to Kenyan high school science teachers, and attempts to tackle these problems are in line with official government goals such as the STEM Model Schools intervention program.[8]

The context in Tanzania is in some ways similar. Tanzania recently launched their Policy of Education and Vocational Training of 2014, which identified different challenges affecting the quality of education on the national scale. Such challenges include lack of laboratories for science subjects, insufficient numbers of teachers particularly in science subjects and mathematics, and poor morale of some teachers due to poor teaching (and living) environments reflective of poor funding. Furthermore, the policy indicates poor utilization of ICT in education, poor mastering of learning and teaching languages, and curricula that do not reflect the globally competitive scene in science. Thus, applications of practical science activities through computers could help address some of the problems that have been so officially identified.

Graduate students in materials science and even chemistry often have exceptional expertise with advanced computational software related to their research. This is especially true in research environments such as Africa that may lack the appropriately extravagant financial resources to secure big-ticket analytical instrumentation.

Thus, there is a natural opportunity for collaboration: between high school science teachers who are in need of scientific educational content for computers, and materials science graduate students who have an abundance of such expertise. The genesis of such a project was formulated at a conference[9] of materials science graduate students from the US and Africa, among which happened to be at least two former high school chemistry teachers. Thus two materials science graduate students decided to develop high school chemistry lesson plans for delivery on computers in Kenya and Tanzania. Computer-based lesson plans for high school chemistry students are by no means new[10] – but there is a need to develop their specific application to the unique environment of East Africa, especially with a mind towards widespread and free distribution. Indeed, chemistry that is community-specific is often advantageous over generic implementations.[11]

The chemistry lesson plans were developed with the specific cultural and environmental context of Kenya and Tanzania in mind. The lesson plans were field-tested in Tanzania at Msalato Secondary School in Dodoma City, Tanzania. The study focused on evaluating the effectiveness of using virtual lab tools to teach chemistry, particularly topics related to molecular bonding and compound structure. The implementation of the lesson plan calls only for free software – no expensive licenses, obscure materials, or bulky laboratory equipment required. The software is provided here in the links at the end of this manuscript.

METHODS

The lesson plans would have to feature software that was relatively lightweight – many of the target computer labs had relatively old machines. The lesson plans would have to feature programs that could be installed and not rely on internet access – many of the target computer labs did not have active internet connections, although files and programs could be shared relatively easily by USB key amongst networks of high school teachers. And finally, the lesson plans would have to feature science content relevant to the East African context – so as not embark on an imperialistic collaboration.

It was decided to use *Vesta*, a free visualization program developed by JP Minerals.[12] It was furthermore decided to use real crystallography data from the Open Crystallography Database.[13] Two lesson plans (one on VSEPR structure and one on unit cells) were developed using these resources. To add local context, the lesson plans included readings on local materials: a natural product and a mineral, both of whose chemistries were featured in the lesson plan as well. The full lesson plans and all associated materials (including software packages, data sets, and student worksheets) are available as Externally-Hosted Supporting Material in the Associated Content section noted at the end of this manuscript.

The lesson plans were piloted in Tanzania at Msalato Secondary School, in Dodoma City, Tanzania. Forty-one form-five students were selected for the study – the students had not previously studied molecular bonding, compound structure, VSEPR structure, or unit cells. Students were divided into two groups. The twenty students in Group A were subject to traditional chemistry lessons on VSEPR structure (not detailed here), whereas the twenty-one students in Group B were subject to the same traditional lessons plus the computer-based VSEPR lessons developed in this project. Both groups of students were given a standard (but challenging) test on the content material after the lessons. After the content test, all students in both groups were exposed to the software, and a questionnaire was used to furthermore evaluate the success of the developed lesson plans.

RESULTS

Table 1. Content Test Results

Group	*Average Score (out of 100)*
A (n=20, traditional lesson)	53.9
B (n=21, traditional lesson plus developed computer lesson)	65.2

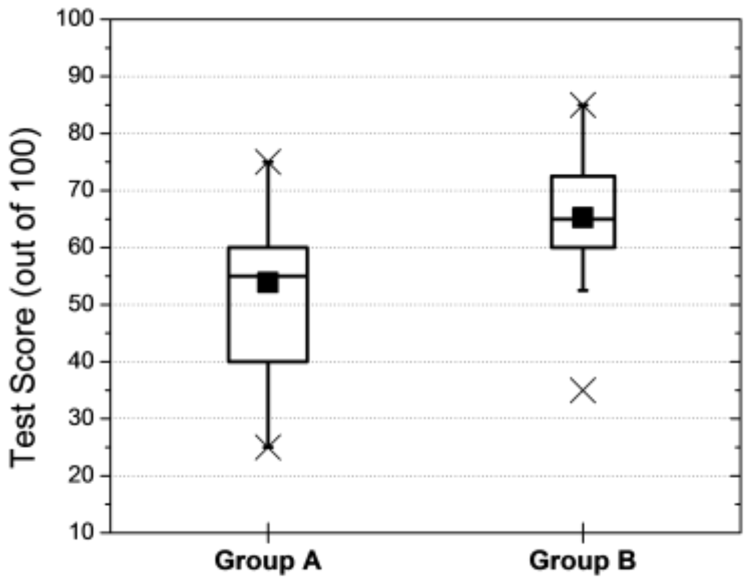


Figure 1. Box plot of content test scores. Group A students were given a traditional lesson, whereas Group B students were given a traditional lesson plus the developed technology-based lesson. Box whiskers represent 1.5 IQR. Squares refer to means and Xs represent maxima and minima.

Table 2. Questionnaire Results. Scored on a scale of 1 = Strongly Disagree to 5 = Strongly Agree.

Statement	*Average Score (n=41)*
The bonding concepts were well illustrated using the software tool	4.4
The structure of the molecules was easier understood using the software tool	4.8
I could easily name and describe the molecular structure using the software tool	4.6
I could properly see and measure the angle between molecules using the software tool	4.2
I would recommend the teachers to use this software when teaching bonding concepts	4.8
The lesson was more interesting using the software tool	4.7

Students who participated in the lesson plan developed here scored better on tests than students who were not exposed to the lesson plan. The tests asked students to recall and analyze content from the lesson, and the improved achievement with students who worked on the computer lesson plans suggests that such lesson plans are useful classroom tools. We do note that alternative explanations may exist – perhaps it is not the lesson plan themselves, but just the extra time that students from the experimental group spent studying the topic that explains the improved test scores.

In any case, students were enthusiastic about the chemistry lessons on computers. Especially in a high school classroom setting, such enthusiasm in itself may be a meaningful victory. No students disagreed with any of the statements on the questionnaire, and furthermore when students were asked whether they prefer computer-based lessons or traditional lessons, they unanimously chose computer-based lessons or both, with none preferring traditional lessons. We do note that there may be some cultural issues at play here (reluctance for students to disparage authority, for example), but we choose to interpret the results in the better light.

DISCUSSION AND CONCLUSION

We were pleased to find that the developed lesson plans were well-received in classrooms in Tanzania. The software was successfully installed on computers, teachers were successfully able to deliver the lessons, and students were able to learn about chemistry more successfully than they might have otherwise. Furthermore, the learning experiences were met with universal enthusiasm from students.

The “collaborative exchange” referenced in the title of this work is actually multidimensional. In one dimension, we have collaboration between materials science researchers and high school science teachers. Advanced software tools that are primarily developed for materials science research are often at the cutting edge of modern technology, and it is important to create conduits for this technology to filter down into classrooms of young budding potential scientists. With only minimal repurposing, and a clear set of instructions, such software can be successfully implemented in classrooms, as we have shown both in this project and in previous similar projects.[14] High school teachers gain access to new and exciting technology-based lessons, and materials science researchers gain an opportunity for community outreach which is often an important goal of higher education academia. Such collaboration is important and impactful.

The other dimension of the collaboration featured here is the international dimension – one of the leaders of this project was American (although mostly based internationally) and the other leaders were African (Kenyan and Tanzanian). Such collaborations are often nontrivial, as other authors have noted.[15] The organic nature of this particular collaboration’s genesis illustrates the opportunities gained when bringing geographically disparate young researchers together in conferences such as

JUAMI[9] – as others have also demonstrated.[16] We furthermore note that this collaboration does not feature a one-sided exportation of resources from the US to Africa. The lesson plans were tested in African classrooms and now that they are published here, they are completely free to reproduce, distribute, and modify, without limit, by educators in Kenya and Tanzania and elsewhere. We hope that this project may inspire other similar technology-based collaborations between researchers and teachers, in Africa and beyond.

ASSOCIATED CONTENT

Externally-Hosted Supporting Material

Supporting material including complete lesson plans and software for full implementation of described lessons are hosted at https://chemistryoncomputersineastafrica.blogspot.com/ and also at the AfricArXiv Preprint Server at https://osf.io/preprints/africarxiv/.

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REFERENCES

(1) Duermeijer, C.; Amir, M.; Schoombee, L. Africa generates less than 1% of the world's research; data analytics can change that https://www.elsevier.com/connect/africa-generates-less-than-1-of-the-worlds-research-data-analytics-can-change-that.

(2) Optimism for Africa. *Nat. Mater.* **2018**, *17* (3), 209–209.

(3) *Chemistry for Sustainable Development in Africa*; Gurib-Fakim, A., Eloff, J. N., Eds.; Springer

Berlin Heidelberg: Berlin, Heidelberg, 2013.

(4) Cole, T. The White-Savior Industrial Complex. *The Atlantic*. 2012.

(5) Mammino, L. Teaching Chemistry in a Historically Disadvantaged Context: Experiences, Challenges, and Inferences. *J. Chem. Educ.* **2011**, *88* (11), 1451–1453.

(6) Shizha, E. Are We There yet? Theorizing a Decolonizing Science Education for Development in Africa. In *Decolonizing Philosophies of Education*; SensePublishers: Rotterdam, 2012; Vol. 554, pp 163–176.

(7) Nordling, L. How Decolonization Could Reshape South African Science. *Nature* **2018**, *554* (7691), 159–162.

(8) Oduor, A. New Plan to Make Maths and Sciences Interesting. *Standard Digital (Kenya)*. 2017.

(9) Wenderott, J. US and African Students Unite around Materials for Sustainable Energy at Second JUAMI. *MRS Bull.* **2016**, *41* (08), 632–633.

(10) Jennings, A. S. The VSEPR Challenge: A Student's Perspective. *J. Chem. Educ.* **2010**, *87* (5), 462–463.

(11) Collins, S. N.; Appleby, L. Black Panther , Vibranium, and the Periodic Table. *J. Chem. Educ.* **2018**, *95* (7), 1243–1244.

(12) Momma, K.; Izumi, F. VESTA : A Three-Dimensional Visualization System for Electronic and Structural Analysis. *J. Appl. Crystallogr.* **2008**, *41* (3), 653–658.

(13) Gražulis, S.; Chateigner, D.; Downs, R. T.; Yokochi, A. F. T.; Quirós, M.; Lutterotti, L.; Manakova, E.; Butkus, J.; Moeck, P.; Le Bail, A. Crystallography Open Database – an Open-Access Collection of Crystal Structures. *J. Appl. Crystallogr.* **2009**, *42* (4), 726–729.

(14) Rodenbough, P. P.; Vanti, W. B.; Chan, S.-W. 3D-Printing Crystallographic Unit Cells for Learning Materials Science and Engineering. *J. Chem. Educ.* **2015**, *92* (11), 1960–1962.

(15) Jansen-van Vuuren, R. D.; Buchanan, M. S.; McKenzie, R. H. Connecting Resources for Tertiary Chemical Education with Scientists and Students in Developing Countries. *J. Chem. Educ.* **2013**, *90* (10), 1325–1332.

(16) Li, Y. C.; Melenbrink, E. L.; Cordonier, G. J.; Boggs, C.; Khan, A.; Isaac, M. K.; Nkhonjera, L. K.; Bahati, D.; Billinge, S. J.; Haile, S. M.; et al. An Easily Fabricated Low-Cost Potentiostat

Coupled with User-Friendly Software for Introducing Students to Electrochemical Reactions and Electroanalytical Techniques. *J. Chem. Educ.* **2018**, *95* (9), 1658–1661.