Case for Integrating Computational Thinking and Science in a Low-Resource Setting

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ABSTRACT

There is a growing need to use computers to formulate problems and their solutions across domains. It has thus become imperative that students across the globe be able to work with computing to express themselves. However, teaching computer science in a traditional way may not be possible in all settings. We studied a method to integrate computational thinking, the ability to express problems and their solutions to a computing device, into an existing science classroom with the goal of deepening learning in both science and computational thinking in a low-resource setting in Nepal. In this note, we present findings from the study. The proposed curricular method acknowledges local differences and presents a way to adapt to those differences through adaptable multiple layers of activities and representational variability. We hope that interested educators and development practitioners would try our method in classrooms.

CCS CONCEPTS

• **Social and professional topics → Computational thinking**; **K-12 education**; • **Applied computing** → *Interactive learning environments*;

KEYWORDS

ICTD; ICT4D; educational technology; computational thinking; CT; agent-based simulation, NetLogo

ACM Reference Format:

Aakash Gautam, Whitney Elaine Wall Bortz, and Deborah Tatar. 2017. Case for Integrating Computational Thinking and Science in a Low-Resource Setting. In *Proceedings of ICTD '17*. ACM, New York, NY, USA, Article 4, 4 pages. https://doi.org/10.1145/3136560.3136601

1 INTRODUCTION

Many prior works on ICTD have focused on access to infrastructural resources, including computers. As famously demonstrated by the One Laptop Per Child (OLPC) project [13], from a learning perspective, infrastructure alone is not enough to produce meaningful learning. Additional key ingredients include both usable software and the match between the affordances of the software, the instructional purposes of the unit, and other supporting materials and student activities [4, 10]. These elements and the matches between them, that is, the way the underlying infrastructural resources can be *used*, constitute the prospects for attaining success [1, 6].

Some prior ICTD work has focused on enabling the use of the underlying infrastructure, for example, by providing educational games in mobile phones outside of schools [5], delivering content through mobile phones [2], blending online and in-person instruction [3], and exploring a technology-centered tutoring system [8].

This note takes the exploration of the use of technology in context to a deeper level. It presents a method of introducing computers with the joint goals of (1) deepening understanding of science and (2) promoting *computational thinking*. Computational thinking (CT) is the ability to "formulate problems and their solutions so that the solutions are represented in a form that can effectively be carried out by an information-processing agent" [15]. In a simplified form, CT is being able to *think like a computer scientist.*

There is a growing consensus among educators about CT as a necessary skill permeating many domains [15]. Likewise, studies have posited the importance placed on computers and their perceived value by public in rural settings [9]. Despite these interests in computing, little is known about how to adapt materials and practices to create conditions of receptivity. Barriers include high-level "wicked problems" [11] like gender bias [9], the benefit of connecting abstract computational ideas to actual life experiences [7], and the need to avoid implying that the only path to learning is through regular access to computer technology. An overly computer-centric perspective on learning may be discouraging to those who do not and cannot have regular access. Students' varying backgrounds, interests and aspirations require teaching high-order thinking like CT with local adaptation in low-resource settings.

The curricular approach we advocate utilizes multiple representations, both on and off the computer, combining the introduction of CT with recognizable components of education, in this case, Biology/Chemistry, that give students access to different facets of knowledge required to have deep understandings. In doing this, we also focus on the strengths of in-classroom, face-to-face instruction.

We have designed an integrated curriculum in which the teacher moves students through experiences with multiple representations of a science phenomenon. As shown in Table 1, some of the representations are on paper, some are student created or modified, some represent science through animated, playable simulations, and some represent science through programming code. The instruction is governed by a driving question, in this case, "where does the carbon go" during photosynthesis and carbohydrate catabolism. Modeling and simulation are by themselves important aspects of

ICTD '17, November 16–19, 2017, Lahore, Pakistan

ACM ISBN 978-1-4503-5277-2/17/11…$15.00
https://doi.org/10.1145/3136560.3136601

Table 1: Layered activity used in the instructional module

Kinds of Representations	Pedagogical affordance(s)	Objects and Processes
Macroscopic digital representation	Introduced students to a science phenomenon similar to the real-life world they had experienced.	Dynamic objects and processes that were recognized as "real-life" such as cows, plants, sun, eating, dying, and growing.
Microscopic overlay	Introduced the idea that macroscopic objects and processes are influenced by microscopic, chemical objects and processes.	Contextualized dynamic digital representations of molecules and molecular processes interacting with the macroscopic objects.
Group poster creation	Conveyed that science can be understood by different kinds of representations of objects and phenomena, highlighting different facets of knowledge.	Static student drawings and their explanations of the observed phenomena, and explanatory mechanisms.
Science fact sheet	Helped students connect the knowledge in the other representations with more standard scientific representations, such as chemical formulas.	Static written text, images, and chemical formulas to explain the phenomena like in a textbook.
Code-based representations	Introduced the idea that representations are made to serve particular purposes, that the student can create, change or modify representations and that science may be represented at different levels of granularity and accuracy.	Text based code defining objects, properties and procedures that can be edited and uploaded to change the simulation.

CT, but the introduction to CT is furthered by creating a context in which students can use programmatic representations to change and explore the phenomenon. The curriculum directs the students towards inquiry about the chemical basis of biological processes.

2 STUDY

2.1 School Setting

We conducted our study in a school, established in 2013, 14 kms from Kathmandu, Nepal, that aims to provide interest-based education[1]. Despite a focus on STEM (Science, Technology, Engineering and Mathematics), the school adheres to the central government's syllabus, with instruction primarily delivered in English. The school recruits and boards students from several rural areas of the country, most of them from families with limited financial resources. During the 2016-17 school year, 125 co-ed students ranging from 6-16 years old were enrolled. Sixteen (9 female, 7 male) were enrolled in the 7th grade and participated in this study. Although the setting is rural, from a Nepalese point of view, the school is fairly accessible through public transport and has Internet connectivity. The school had three functioning computers in a room with battery backup, access to which was restricted to students in 9th and 10th grade.

2.2 Curricular Approach

We conducted a two-week long intervention, involving 35 instructional hours. A Nepali author of this note led the instruction, with support from the local science teacher. There were four computers in the class including one of the author's laptop, which meant each computer was to be shared by four students. To mitigate inequality in engagement and learning experience when sharing a computer [10], students discussed their plans in groups prior to working on the computer. We also asked students to rotate their position while working on the computer.

The science content in the module adhered to the national 7th science curriculum to teach photosynthesis and the natural carbon cycle. The left-most part of Figure 1 shows the level of instruction students had received. Our module tied that level of representation to the chemical processes involved in photosynthesis and carbohydrate catabolism in animals. This approach opens up the idea of conservation of matter which can lead to the introduction and balancing of related chemical equations. The representations utilized during the intervention, their affordances, and the objects and processes they illustrated are listed in Table 1.

Students first worked on an introductory simulation that had simple representation of familiar, macroscopic real-world phenomenon. In this representation, plants grew, cows moved around, and the sun shined. The cows ate plants and died if there were no plants. By changing sliders and buttons, students could explore the relationship between the number of plants, the number of cows, and longevity. They moved into exploration of the microscopic phenomena by displaying hugely exaggerated representations of carbon forms and their transformation through different chemical processes (see the center image in Figure 1). Students worked in groups of four to create their own representations: posters they drew and described what they thought was going on in the simulation. They presented the poster to the class for discussion. Other, more standard scientific representations were presented via the "science fact sheet", a single-page document with verbal descriptions, chemical formulas and illustrative pictures that highlighted some of the science concepts. A last set of representations were introduced through exposure to the code that implemented the simulation. This enabled the important idea that the expression of objects could be modified by writing commands and blocks of code. Students studied snippets of the code to understand the model, and subsequently discussed and implemented an extension of the model by writing code.

2.3 System Description

A central part of the curriculum involves working with an animated digital simulation of the natural carbon cycle, and interacting with the macroscopic and microscopic representations of the natural carbon cycle implemented using agent-based modeling in NetLogo

[1] http://news.mit.edu/2015/help-rebuild-bloom-nepal-school-destroyed-earthquakes-0612

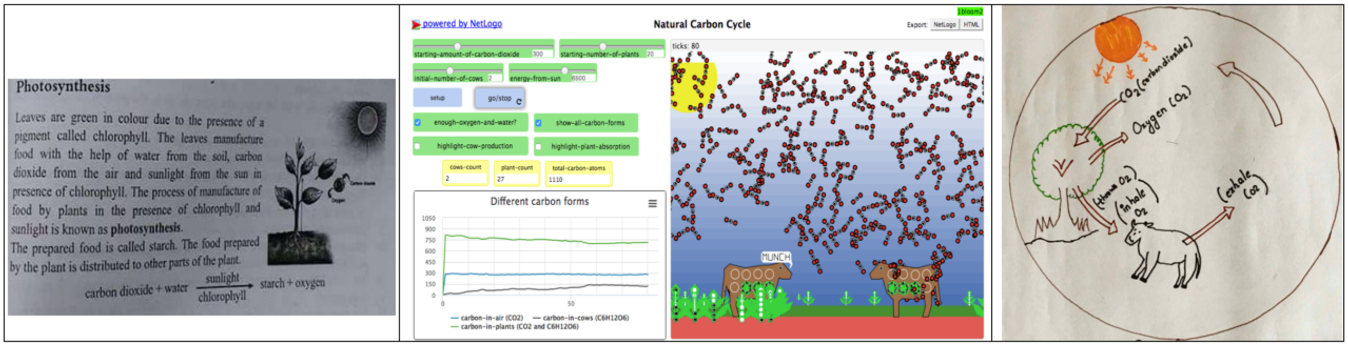

Figure 1: Textbook representation of the phenomenon (left), the overlay of microscopic and macroscopic representations that we presented during our intervention (center), and one group's drawing of the science phenomena (right)

[14]. The simulation runs in any Internet browser and therefore does not require local software installation. In general, the system is a single page web application in which the simulation and modeling are executed on the client side once the first page loads. Therefore, the system is established through a simple local HTTP server and does not depend on Internet connectivity. However, for the study, we recorded log entries of student interaction with the computer so we served the web application through a remote server and this required Internet connectivity.

2.4 Data Collection and Analysis

After engaging in an IRB-approved consent process at the beginning of the intervention, we conducted an attitudinal assessment to evaluate students' self-confidence with, interest in, values for, and identification with computing. Use of the simulation was logged including keystrokes and interface-based changes. Student worksheets and posters were collected for analysis. We also conducted a post-performance assessment.

Posters and free-text comments about attitudes were analyzed using a grounded theory approach [12] by researchers familiar with the project, including the authors. Themes emerging from the content and pictorial depiction were identified and discussed, and possible alternative conceptions were identified as well. Variation in student activity with the computers was analyzed through log data. Furthermore, post-performance assessment was evaluated against an established rubric to measure the students' understanding of science and CT. A few emergent findings are reported here.

3 FINDINGS

3.1 Interest in Computing and Apprehension

Students had played mobile games but were unfamiliar with the concepts of simulation and modeling. Previous use of computers was confined to two students who had typed in Microsoft Word and drawn in Microsoft Paint a few times. Most had seen others use computers but had never actively used one. Despite the limited exposure to computing, most students held it in esteem. A student ([S7]) wrote, "*I think computing is very important for all of us because now days [nowadays] most of the people depends [depend] on computing for their work.*" While students were interested and excited, they were also initially apprehensive. Three groups hesitated to change slider values during the initial exploration out of fear of "making the system go bad".

3.2 Summary of Key Science Learning Observations

- The students used mechanistic phrases like "*throw out carbon dioxide*" and "*take in oxygen*" but weren't familiar with the random motion of molecules. The simulation encouraged students to inquire about movement of molecules and the right conditions necessary for reactions to occur.
- Students knew that air contained carbon-dioxide and that its chemical formula was CO_2. However, none of the students could use the formula to conclude that carbon-dioxide contains one carbon atom and two oxygen atoms. The microscopic representation of carbon-dioxide molecule that showed atoms in CO_2 drove students to connect the subscripts with the atomic count.
- Students described carbon-dioxide gas as containing CO_2 (rather than *being* CO_2) and therefore initially identified the carbon atoms in the simulation as carbon-dioxide and the depiction of the molecule with all three atoms as representing the gas. The question "what are the blacks and red dots?" led to a class-wide discussion on Day 3, clarifying the misconception.
- They knew about photosynthesis but not about breakdown of glucose in animals. Three of the four groups studied the graph, which showed carbon amounts in atmosphere, plants, and cows to hypothesize the transformation of carbon forms in animals.
- Fifteen of the sixteen students identified that water was missing from the simulation. This created the opportunity for this class of students to build into the simulation based on their own understanding of what was important about the science.

3.3 Summary of Key CT Observations

- None of the students were familiar with simulation or modeling at the start of the intervention. As we progressed through the activities, students evaluated and critiqued in terms of things that were accurate, inaccurate, and missing from the model.
- Students expressed their lived experiences through single-lined commands by modifying shapes of objects. The most common changes involved changing cows to people, plants to flags and tree, and the sun to hills and mountains.

- Because the students thought that it was important to represent water, they undertook a project they thought was important: extending the code to implement clouds and rainfall.
- Students were able to implement clouds and rainfall by identifying and discussing elements in the simulation that were similar to the extension they wanted to create. They abstracted common properties and methods from the existing code.
- With the instructor's support, the students divided the task into smaller tasks, and planned and discussed ways to complete those tasks. The planning and discussion occurred without a computer and pushed the idea that CT is not just about computers.
- By the end of the task, students had created two new objects and three methods which highlighted their understanding science and understanding of CT concepts such as method call sequences, operators, and abstraction.

4 DISCUSSION AND CONCLUSION

4.1 Deepening Science Learning

Under the conditions in the study, students appeared to learn quite a lot of important science. The students were familiar with a single form of representation i.e. the textbook depiction of the process. Although the students had read about concepts such as atomic composition, molecular movement and necessary conditions for reactions to occur, the representations in the text book were static and separated each idea into an isolated unit. As shown in Figure 1, the representation of photosynthesis in the book showed a single molecule with arrows labeled oxygen and carbon-dioxide. It did not show the atomic structure of oxygen or carbon-dioxide. Our dynamic representation containing atomic structure of carbon-dioxide made it easier for students to connect different ideas. Furthermore, the multiple representations presented through layered activities pushed students to further explore the science phenomenon such as by using graphs alongside the simulation.

4.2 Deepening Computational Thinking

Students moved from initial apprehension to considerable sophistication in the two-weeks of instruction. They certainly learned something about programming (because they were able to implement changes), but they were actively engaged in discussing elements of the models, and formulating and expressing solutions. In some sense, the low-resource setting, with only four computers for 16 students makes it abundantly clear that only some access is required. Most of the pedagogical challenge is provoking a computational way of thinking.

4.3 Integrating Science and CT

This paper presents initial evidence of student learning drawn from a study in which we taught both Science and CT in a low-resource environment. The method that we used prioritized representations both on and off the computer that moved fluently between science and CT and back again. We believe that this method worked because students were continually able to draw on elements that they already understood to make sense of novel elements. In this case, the students were highly motivated and had quite a bit of textbook knowledge. It remains to be seen whether the method could be successful in environments with less motivated students.

However, some optimism may be drawn from the fact that the underlying system is attentive to a range of conditions that prevail in low-resource schools. It does not require many computers or much investment in creating access. Even devices that simply give browser access could be used. Furthermore, these layered representations can provide different learning opportunities for students who bring different strengths and knowledge bases to the learning task. These students thought it was important to implement clouds and rainfall; others might consider it important to implement detritivores, showing more orientation towards the underlying chemistry or lions, showing more orientation towards ecology.

A classroom teacher may not use our system the way we did during the intervention. They may not focus on the code-based model and instead focus on the static representation through the science fact sheet or focus solely on the visual simulation. However, evidence from our intervention in Nepal suggests that the richness in the learning environment, particularly through variability in the representations, supports students at different levels to explore and discover while providing flexibility for instructors to use the tool as they need for their class.

REFERENCES

[1] Paul Braund and Anke Schwittay. 2006. The missing piece: Human-driven design and research in ICT and development. In *Information and Communication Technologies and Development, 2006. ICTD'06. International Conference on.* IEEE, 2–10.

[2] Cynthia Breazeal, Robin Morris, Stephanie Gottwald, Tinsley Galyean, and Maryanne Wolf. 2016. Mobile devices for early literacy intervention and research with global reach. In *Proceedings of the Third (2016) ACM Conference on Learning@ Scale.* ACM, 11–20.

[3] Edward Cutrell, Jacki O'Neill, Srinath Bala, B Nitish, Andrew Cross, Nakull Gupta, Viraj Kumar, and William Thies. 2015. Blended learning in Indian colleges with massively empowered classroom. In *Proceedings of the Second (2015) ACM Conference on Learning@ Scale.* ACM, 47–56.

[4] Paul DiMaggio, Eszter Hargittai, Coral Celeste, and Steven Shafer. 2004. From unequal access to differentiated use: A literature review and agenda for research on digital inequality. *Social inequality* (2004), 355–400.

[5] Matthew Kam, Anuj Kumar, Shirley Jain, Akhil Mathur, and John Canny. 2009. Improving literacy in rural India: Cellphone games in an after-school program. In *Information and Communication Technologies and Development (ICTD), 2009 International Conference on.* IEEE, 139–149.

[6] Patrick J McEwan. 2015. Improving learning in primary schools of developing countries: A meta-analysis of randomized experiments. *Review of Educational Research* 85, 3 (2015), 353–394.

[7] Na'ilah S Nasir, Ann S Rosebery, Beth Warren, and Carol D Lee. 2006. Learning as a cultural process: Achieving equity through diversity. *The Cambridge handbook of the learning sciences* (2006), 489–504.

[8] Benjamin D Nye. 2015. Intelligent tutoring systems by and for the developing world: a review of trends and approaches for educational technology in a global context. *International Journal of Artificial Intelligence in Education* 25, 2 (2015), 177–203.

[9] Joyojeet Pal, Meera Lakshmanan, and Kentaro Toyama. 2007. "My Child will be Respected": Parental perspectives on computers in rural India. In *Information and Communication Technologies and Development, 2007. ICTD 2007. International Conference on.* IEEE, 1–9.

[10] Udai Singh Pawar, Joyojeet Pal, and Kentaro Toyama. 2006. Multiple mice for computers in education in developing countries. In *Information and Communication Technologies and Development, 2006. ICTD'06. International Conference on.* IEEE, 64–71.

[11] Horst WJ Rittel and Melvin M Webber. 1973. Dilemmas in a general theory of planning. *Policy sciences* 4, 2 (1973), 155–169.

[12] Anselm Strauss and Juliet Corbin. 1994. Grounded theory methodology. *Handbook of qualitative research* 17 (1994), 273–85.

[13] Mark Warschauer and Morgan Ames. 2010. Can One Laptop per Child save the world's poor? *Journal of international affairs* (2010), 33–51.

[14] Uri Wilensky and I Evanston. 1999. NetLogo: Center for connected learning and computer-based modeling. *Northwestern University, Evanston, IL* 4952 (1999).

[15] Jeannette M Wing. 2006. Computational thinking. *Commun. ACM* 49, 3 (2006), 33–35.