Using the Learning Cycle in Computer Science Education
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Abstract

The learning cycle was originally developed in science education and has been used for over fifty years. After introducing constructivist learning theory and early development of the learning cycle, this white paper explores two recent applications in computer science education: CS-POGIL and the microlab learning cycle. A research program is proposed to answer a list of research questions about using the learning cycle in Computer Science education. A dissemination plan is included to involve other Computer Science instructors in the use of the learning cycle.

Historical Background

Constructivism “is a learning process which allows a student to experience an environment first-hand, thereby giving the student reliable, trust-worthy knowledge. The student is required to act upon the environment to both acquire and test new knowledge.” [Wikipedia] This approach to learning theory is not new; some prominent historical theoreticians and practitioners are John Dewey (1859–1952), a leading American educator, Maria Montessori (1870–1952), an Italian physician/educator and founder of the Montessori approach to early childhood education, Lev Vygotsky (1896–1934), a Russian psychologist who theorized about the role of culture and language in intellectual development, and Jean Piaget (1896–1980), a Swiss developmental psychologist who studied cognitive and moral development in children.

Piaget described his work as genetic epistemology. Epistemology is the study of the acquisition of knowledge and “genetic” focuses on how humans develop cognitively from birth throughout their lives. Two of his later books, The Origins of Intelligence in Children (1952) and The Growth of Logical Thinking from Childhood to Adolescence (1955), have had profound impacts on the American educational system and he is indirectly responsible for the introduction of “hands-on learning”. Piaget hypothesized four states of intellectual development:

- Sensorimotor stage – 0 to 2 years, knowledge acquired through movement and senses; the child is very egocentric
- Preoperational stage – 2 to 7 years, develop motor skills, egocentrism weakens
- Concrete operational stage – 7 to 12 years, logical thinking starts to develop based on concrete aides
- Formal operational stage – 12 years onward, development of abstract thought, children can think about thinking, may be slow to develop in some children and not present even at college age

Piaget built a theoretical model based on three types of schema (behavioral, symbolic, and operational) that form a mental framework that develops as children interact with their physical and social environments. Two processes are responsible for reinforcing or modifying these schema:

- Assimilation is when a child responds to a new event in a way that is consistent with an existing schema and reinforces the schema
- Accommodation is when a child either modifies an existing schema or forms an entirely new schema

Intellectual development occurs as schemata are acquired or modified, largely due to accommodation.

Robert Karplus was a world-renown theoretical physicist who calculated the magnetic moment of the electron while at the Institute for Advanced Study before moving to UC Berkeley. His “second career” was in science education [Fuller, 2002]. He received initial funding from the NSF in 1959 for a 20 year effort called the Science Curriculum Improvement Study. As part of this effort in 1962 he introduced the learning cycle that has three stages [Karplus, 1962]:

- Exploration: Students explore a problem; may receive guidance towards a solution; largely an assimilation activity
Recent Applications of the Learning Cycle

Process-oriented guided inquiry learning (POGIL) is based on Karplus' learning cycle. It originated in college chemistry departments in 1994; there are now well over 1000 implementers in a wide range of disciplines in high schools and colleges around the country. POGIL uses guided inquiry based on the learning cycle as the basis for many of the carefully designed materials that students use that guide them to construct new knowledge. POGIL develops process skills such as critical thinking, problem solving, and communication through cooperation and reflection.

Although POGIL is widely used in physics and chemistry it has only been recently used in Computer Science Education. Clifton Kussmaul [2012, 2013], Helen Hu [2014] and Mathew Lang are leaders in this effort. Rahman Taskakkori, co-author of this white paper, uses a POGIL-like style of teaching in his classes which includes Database [Tashakkori, 2013]. In that course, he provides students with short questions at different stages of his lecture aiming at exploration of the concepts as a team. All the teams are formed early in the semester based on the survey of their courses, experience, and skills. During the lecture Dr. Tashakkori asks the students to try to answer the questions by expanding on the lecture material. He actively encourages students to be involved with the development of the solutions. He provides incremental guidance during the process by acquiring input from all teams and requiring of them to report on the gradual progress. The short questions are designed such that students are engaged and work effectively in collaboration that results in new knowledge.

Barry Kurtz, co-author of this white paper and the last PhD student of Bob Karplus, has developed and tested the microlab learning cycle for Computer Science education. A microlab is a 5-10 minute activity during lecture that actively involves students in the learning process [Kurtz, 2012, 2014]. This research work has been supported by multiple NSF grants [DUE grants]. We illustrate the learning cycle for a specific problem where a student is asked to build a binary tree given the preorder and the inorder traversals. During the exploration phase in a logical microlab the student is asked to construct the tree graphically; a correct solution to a particular problem is shown to the right.

Building on these experiences, in the invention phase it is the instructor’s job to guide students toward an algorithm that will build the binary tree based on the preorder and inorder traversals. An instructor can begin by eliciting observations from the logical microlab activity, such as those below.

- The first node in the preorder traversal is the root of the tree.
- This node divides the inorder traversal into the inorder traversal of the left subtree and the inorder traversal of the right subtree.
- Using the lengths of these two inorder traversals, the left and right preorder traversals can be determined.
- The left and right subtrees can be built recursively.
- One or more base cases are needed to stop the recursion.

Discussion of these observations then leads to a pseudocode algorithm, such as:
If the traversals are empty, return null
Create the root using the first node in the preorder traversal
If the traversal has a single node, return the root
Find the preorder and inorder traversals of the left subtree
Use recursion to build the left subtree
Find the preorder and inorder traversals of the right subtree
Use recursion to build the right subtree
Return the root

During the application phase students are expected to develop program code for methods using a “drag and drop” approach with code magnets. After students place the magnets as desired, they press the Finalize button to compile their code and perform unit testing. The list of available magnets for the buildBinaryTree method is shown to the left below and a student building a method on a 7” tablet is shown to the right.

The microlab learning cycle has been used at three universities (Appalachian State, Stony Brook, and UNC Greensboro) but requires more widespread usage and more detailed evaluation to measure the effectiveness of using the learning cycle in Computer Science education.

Research Program
The proposed research program will have two major thrusts:

(1) Based on the work of Clif Kussmaul, Rahman Tashakkori and others, investigate how topics in Computer Science can be introduced using a POGIL approach. Chemistry and Physics are data driven, in the sense that experimental measurements (the exploration phase) lead to a theory of relationships between variables (the invention phase) that can be applied to the solution of related problems (the application phase). How can topics in Computer Science be adapted to a similar approach?

(2) How can the microlab learning cycle be expanded beyond the current topics in the CS1, CS2, and data structures courses? How can development of new materials be made cost effective and not be dependent on external funding from the NSF or other agencies?

In both cases the goals are to:

- Develop techniques for measuring the effectiveness of using the learning cycle as compared with traditional educational approaches
- Investigate how the learning cycle can improve student retention and diversity
• Develop techniques to motivate and to train Computer Science instructors to use the learning cycle in their teaching activities.

The research program will also provide significant information on the implementation overhead as some computer science concepts may provide challenges in implementation.

Research Questions

The above research program attempts to answer many detailed research questions about the use of the learning cycle, including:

• How does the exploration phase of the learning cycle prepare students for the introduction of new concepts? How much guidance should be provided?
• How does guided discovery help build confidence in students, particularly those from underrepresented groups such as women and minorities?
• What teaching techniques can be used to make the invention phase interactive, even when it takes place in a lecture setting?
• What activities should be part of the application phase?
• How can activities outside of the classroom, such as closed lab sessions or programming assignments, fit into the learning cycle?
• How can smaller learning cycles, each covering a particular topic such as use of the while loop, be organized into larger learning cycles that deal with broader themes, such as problem decomposition?

Dissemination

Once researchers have a better understanding of how to use the learning cycle with a wide variety of topics in Computer Science, we would establish a Learning Cycle Repository and develop online workshops so many Computer Science instructors can become involved in using the learning cycle.

A medium for dissemination of our results will be NSF sponsored workshops as well as the local, regional, and national conferences and workshops. An over-riding goal will be to encourage use of the learning cycle without dependence on external funding sources.

Summary

Constructivist learning theory is the psychological basis for the use of “hands-on” learning in the classroom. The learning cycle is a model of instruction that has worked well in the sciences for more than fifty years. Recently researchers have applied the learning cycle in computer science in two primary ways: CS-POGIL and the microlab learning cycle. We have proposed a research program to explore these new directions and to answer many fundamental research questions. Online workshops will train instructors to use these approaches and a Learning Cycle Repository will promote dissemination.

References

[DUE grants] Developing Software and Methodologies for eBook/Browsers to Enhance Learning (DUE1044572); Transforming Computer Science Education with Microlabs (DUE1122752); Collaborative Research: Innovative Active Learning Using Tablets (DUE 1323178).


[Hu, 2014] Helen H. Hu, Tricia D. Shepherd, Teaching CS 1 with POGIL Activities and Roles, accepted paper at SIGCSE 2014 in Atlanta, GA


