Full Paper: Creating and Assessing STEM Kits for P-12 Teacher Use

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With the continuing call for increased STEM (Science, Technology, Engineering, and Math) education at the pre-college level, teachers are expected to train students in these concepts. However, many teachers do not have the STEM educational background or experience to create opportunities for students to actively engage in learning STEM concepts [1]. Additionally, it is known that inquiry based instruction promotes learning, yet, a recent study revealed that teachers with science related degrees, as opposed to education only degrees, offer inquiry based learning at higher levels [2]. Therefore, there is a need to support teacher delivery of STEM educational concepts. While teachers may receive additional training through local universities or other professional development opportunities, it is challenging to learn from a crash course in a topic or be expected to create an effective lesson plan. However, creating a “kit” for teachers offers a solid starting point to assist teachers in STEM delivery [3]. Following this idea, we developed kits for teacher use; these kits are cost effective, with the materials being widely available. But, most importantly, the kits contain the background STEM information with easy-to-follow instructions that allow teachers to connect the STEM theoretical concepts to practical experiences. This paper discusses (1) how to create the kits, (2) how to train teachers to use the kits, and (3) how to assess the kits from both the teacher and the student learning perspectives.

Introduction

A typical K-12 teacher does not have the required background to teach classes across the breadth of STEM fields. A K-12 teacher generally takes one of two paths to teach in the STEM fields: (1) an education degree or (2) a STEM degree with an education certificate. In the first case, a teacher takes around 12 hours of STEM coursework [4]. In the second case, the teacher’s background is specialized to a specific STEM area (biology, physics, mathematics, computer science, engineering, etc.) [4]. Yet, in either case, there are topic areas in the STEM curriculum in which teachers have limited training; specifically, few teachers have been trained in engineering or computer science. However, teachers do possess strong skills in conveying information to specific student levels. Therefore, if teachers were trained to conduct STEM experiments across the breadth of STEM curricula, they would be able to best deliver the content throughout their courses to pre-college students. Thus, having topic area experts (e.g., college professors) develop STEM activities in their expertise area and train teachers in the fundamental theory of the activities offers an opportunity for universities to collaborate with pre-college teachers to broaden the topics teachers present to their students. Additionally, as many K-12 schools have limited resources, creating an activity “kit” that includes instructions as well as specific materials would promote the use of these activities in classrooms. This collaboration between universities and K-12 teachers creates a sustainable model to introduce a broad array of STEM content activities to engage students and increase the likelihood of sparking student interest in STEM fields.

Creating Activity Kits

To facilitate the incorporation of STEM experiments into classrooms, we propose to create activity "kits". Activity kits for teachers will include: learning objectives, background material on the topic for teachers and students, instructions to present material within the classroom or a teacher script for the activity, class time hands-on activities, student evaluation and assessment materials (i.e., quizzes, tests, homework), frequently asked question (FAQ) sheets, and external resources for additional information or related activities/materials. Kits may be virtual (e.g., accessible via cloud drive) or a combination of virtual and physical, depending on the resources needed for the activity.

Kits will include all information teachers need to complete the activity. Teachers will receive instructions describing the set-up for the experiment and background information. List of external resources will be provided to assist teachers in explaining tricky topics with which they have limited exposure. Additionally, the teacher should review the background material for students, steps in performing the hands-on activity, the "script" describing the activity, and the FAQ sheet—all of which will be provided in the kit. The FAQ sheet will include answers commonly asked questions. The team is also considering an online discussion board, with a 24-hour response time, for managing questions about activities. This could be managed by college students, such as teaching assistants, trained in the exercises. Kits will also contain some of the physical resources needed for the experiment; however, teachers may still need to purchase commonly available items for the experiment. To be cognizant of the cost to offer these experiments, materials selected for use are (1) commonly available at local stores, (2) some materials may be reused across multiple kits, and (3) suggestion for substitution of materials is also provided. Finally, after review and procurement of all materials, the teacher will be able to offer the STEM field specific activity to his/her classroom.

Training the Teachers

To ensure teachers are adequately prepared to offer the experiments in the kits, they would be trained via an in-person workshop before receiving the kits. The workshop is flexible in offerings: a single day training would be on a topic (e.g., "computers"), multi-day or weekend training would review a group of topics (e.g., engineering), and a weeklong training would cover a multiple STEM disciplines. The kits and activities are designed to be delivered in any of these formats, thus allowing teachers multiple opportunities to engage in professional development.

In the workshops, teachers would be trained to use the kits in a highly active learning environment. At the beginning of the training, the learning objectives for each kit are presented. Facilitators then discuss with teachers how the learning objectives may be used to meet state or school requirements, as well as, how to best integrate the kit activity into a course. After this discussion the teachers complete the activity with topic area experts as facilitators. In this manner, teachers are immersed in experiencing the activity, in developing their own questions about the activity, and in considering the types of questions their students would ask. Once the teachers have completed the activity/experiment, they will discuss the experiment with the facilitator to learn more about the fundamentals governing the experiment.

Throughout the activity, facilitators will record any questions asked by the teachers. In addition, if teachers email facilitators with questions after the activity, those questions will also be recorded. As stated previously, FAQs are provided in the kits; however the FAQ list is living and growing with each workshop offering. Updates to FAQ sheets are posted on the cloud drive materials.

Upon completion of the activity, there is a reflection and assessment time. Teachers are provided with student assessment assignments to review. Teachers also complete assessments to gain feedback on the training experience. Facilitators and teachers discuss all the items in the kits, provide tips and suggestions on delivery, and provide information on how the activity covered by the kit is relevant to STEM. An example kit and assessments are included below. This is the first kit created, with all material tested in fifth grade classrooms over three years. The FAQs for the teachers to use were created directly from student questions.

Kit Example: Introduction to Coding Concepts without a Computer

This kit has been designed for and tested in fourth and fifth grade classrooms. The idea came from a fifth-grade teacher looking for a way to introduce coding to her class. The teacher was not familiar with computer programming and requested an activity capable of being completed in a normal classroom with desks, smartboards, chairs, pens, papers, and no computers. The coding kit was designed with several activities, with each activity complementing a prior activity, but also able to be done separately. The kit activities are:

1. Introduction to binary counting [5, 6]
2. Binary bracelets [7]
3. Cryptography [9]
4. Networking and message passing [7]
5. Algorithms
6. Loops [8]

Each kit activity comes with a time recommendation and a matching script although some of the activities come with more than one script and time recommendation. The secondary scripts are written to modify activities for lower grades or to include additional information for higher grades levels. The kit may be used as a two-hour activity or split into distinct sections of about fifteen minutes each and completed over multiple days.

In the introduction to binary, students are introduced to the concept of binary numbers and the idea that computers “read” in binary numbers using the activity from CS Unplugged Website [5, 6] and activities/materials created for a workshop [9]. Students are given chances to learn to count in binary and practice this new skill. This is followed with the binary bracelet activity, which introduces students to the idea of the ASCII code to represent letters, numbers, and symbols. Students use beads of two colors to create a bracelet with their initials using the ASCII code [5-6]. To link this activity to the following cryptology activity, the script recommends explaining that the bracelets now include the student initials in code.

For the code activity, students are taught a simple substitution cypher which shifts letters by a preassigned number. For a shift of 2, the letter A would be substituted with C, B = D, and Z = B. Students are then challenged to decipher coded messages and create their own. This assignment can be extended by having the students practice more encryption techniques, and more advanced techniques can be taught for students in higher grades. This activity is then linked to the networking and passing messages activity. In the message activity, students act as nodes and pass packets of information, such as from an e-mail from the first student to the last. Over passes, nodes that are reading and stealing information are introduced, and techniques for encryption are included. This activity can also be expanded by having students try different setups for message passing, including star and circle.

The last activities in the kit include techniques for teaching algorithms, such as having the students direct the teacher to complete a task. The teacher can have the students break the steps into small segments such as spinning in an unending circle when asked to turn right. Students may also be asked to write out steps to make a salad or sandwich. This concept can be followed up by asking students to have the teacher perform the same steps over and over, to introduce the concept of loops. These activities work very well when paired with scratch or Lego Mindstorms, but can be done independently as well.

Additional kits are being developed to cover basic engineering concepts that explain some of the differences and similarities between engineering disciplines. These activities also focus on the design process in engineering as well as provide background on many engineering ideas such as creep, electrical resistance, and separation of materials.

Assessing the Kits

Two levels of assessment will be completed for this project. First, teachers will complete end of workshop assessment assignments to determine (1) their understanding of the key concept, (2) their understanding of the kit, (3) their expectations of how the kit will be integrated into their classroom, and (4) the effectiveness of the workshop. Open-ended responses will be used for suggestions on kit or workshop improvement. Second, the students performing the kit activities in the classrooms will complete assessment assignments to analyze (1) their understanding of the key concept, (2) the ease of use of the kit, (3) their interest in STEM before and after the activity. For both teachers and students, there are assessment items to help evaluate the knowledge gain, training method, and kit. Table 1 shows a sample of questions from each of the three separate assessments. The training assessment will be completed by the teachers at the training sessions; the kit assessment will be completed by teachers after use in their classrooms; and the knowledge assessment will be completed by both teachers and students after the activity.

Table 1: Assessment Example: Cryptography Activity

Knowledge Assessment	Training Assessment	Kit Assessment
1. What standard exists that allows us (and the computer) to translate letters and symbols on the keyboard into numbers the computer can understand?	1. Do you feel adequately prepared to teach this material to your students? 2. Did you enjoy the activities? 3. Did you enjoy the topics?	1. Did your students have questions that were not on the FAQs? 2. Did the students need more background on a topic?
2. What is the basic thing a substitution cipher does?	3. Did you have questions that were not on the FAQs?	4. Did the students enjoy the topics?
3. Which of the following are substitution ciphers? A. Caesar Cipher B. Book Cipher C. Ranch Cipher D. Encyclopedia Cipher E. A and B	5. Do you feel that the script is detailed enough so you do not need material beyond what we have provided you? 6. How could we improve the training?	5. Was there an activity(ies) with which the students had trouble understand the directions? 6. Did the students enjoy the activities? 7. Did their knowledge of the topic increase?
4. What role does the shift play in the Caesar cipher?	7. What do you feel we could eliminate in the training?	8. Are more students interested in computer related things now?
9. Decipher the following codes if the shift for substitution in the Caesar cipher is 5 • LWIFY OTG	10. What do you feel we need to add to the training? 11. Do you feel that hands-on active learning style will work for your students?	12. Were there any accessibility issues that need to be addressed with the kit itself? 13. Are more students interested in STEM related things now?
14. Why is the Caesar cipher considered insecure?	15. What was your least favorite part of the training? 16. Do you feel we give you enough initial/start up supplies?	17. Do you feel the cost for refill supplies is reasonable? 18. What could we add to the kit?

References:

[1] P. Keeley. “Elementary science education in the K-12 system,” *Science and Children*, 46(9), 8-9, 2009.
[2] T. Kolbe, and S. Jorgenson. “Meeting Instructional Standards for Middle-Level Science: Which Teachers Are Most Prepared?,” *The Elementary School Journal*, 2018; 118 (4): 549 DOI: 10.1086/697540.
[3] T. Ivey, N. Colton, J. Thomas, and J. Utley. “Integrated Engineering in Elementary Education: Tackling Challenges to Rural Teacher Training,” in *Proceedings of the ASEE 123rd Annual Conference and Exposition*, New Orleans, LA, June 26-29, 2016, Paper ID# 15860.
[4] Department of Education. “Secondary Teaching Education Undergraduate Requirements,” Department of Education at University of Michigan. University of Michigan, 2019, http://www.soe.umich.edu/academics/bachelors/secondary-teacher-education/requirements/.
[5] T. Bell, et al., CS Unplugged: Computer Science without a Computer. [Online] www.csunplugged.org. [Accessed 2015]
[6] T. Bell, et al., “Computer Science Unplugged: School Students Doing Real Computing Without Computers,” *Computing and Information Technology Research and Education*, New Zealand (CITRENZ), vol. 13, no. 1, pp. 20-29, 2019.
[7] S. Coffman-Wolph, “Innovative Activities to Teach Computer Science Concepts Inside the Classroom and at Outreach Events,” in *Proceedings of the 2016 ASEE Annual Conference & Exposition*, New Orleans, Louisiana. 10.18260/p.25715, June 2016.
[8] S. Coffman-Wolph, “Fun, Innovative Computer Science Activities for the Classroom and Outreach,” in *Proceedings of the 2017 ASEE Annual Conference & Exposition*, Columbus, Ohio. https://peer.asee.org/28394, June 2017.
[9] S. Coffman-Wolph and K. Gray, “K-12 Classroom and Outreach for Computer Science Concepts,” Workshop presented at *2018 ASEE Annual Conference & Exposition*, Salt Lake, Utah, June 2018.