Abstract

The Kentucky Electronics Education Project (KEEP) uses microelectronics as a theme in developing math, science, and technology curriculum materials drawing on the breadth of content encompassed by microelectronics and the prevalence of electronics in everyday life. KEEP involves curriculum development, teacher workshops, and classroom activities initiated by the educational outreach aspects of two NSF research grants. The emphasis of KEEP is not vocational training; rather it is the use of a real world example as a theme to integrate basic principles from different disciplines. Lesson plans related to circuit building activities connect the process steps to National Math, Science, and Technology Standards. Assessment tools are under development to formalize the educational impact of the hands-on projects. Currently, teachers trained through summer workshops are implementing KEEP into their science classes, utilizing new student assessment tools, and providing pre- and post-evaluations. Based on their feedback, we will determine effective classroom practices, improve the instructional materials, and update the workshop format.

Introduction

The KEEP project attempts to develop units of instruction based upon a series of circuit building activities that incorporates best practice methods, including integrated curricula and performance assessment. Moreover, the hands-on circuit building activities provide a real world activity that is a foundation for math and science application. The project takes efforts to incorporate state and national math, science, and technology standards while attempting to improve the quality of math, science, and technology education for all students by providing professional development activities for current classroom math and science teachers and assisting those teachers with the implementation of the project into their own classrooms. Specifically, the objectives of KEEP are:

- Educate teachers regarding electronic assembly technologies and properties of electronic materials
- Develop curriculum materials and kits
- Organize hands-on projects and fieldtrips
- Solicit education/industry partnerships

Beyond the classroom, KEEP strives to encourage young students to consider technical and engineering careers by exposing them to the exciting possibilities in microelectronics.

One approach to inspiring young students is to lead them through an activity where they can experience the success of building a working circuit from start to finish in a short amount of time. The procedures and kits developed through KEEP have been used by over 300 students grades 6 – 12 to pattern, etch, drill and solder circuits. Younger children in grades 3 – 5 have soldered commercially available kits in Science Day programs. With no prior experience building circuits, it is possible to follow the basic process steps that replicate industrial processes to fabricate electronic circuits.

The impact is further multiplied by training teachers to carry out the same circuit building projects in their own classrooms. Teacher workshops offered in the summer have trained approximately 35 teachers to pattern, etch, drill and solder circuits as well as providing a review of basic electricity and background on each of the process steps such as the chemical reactions occurring in the etching bath. Participants have included math and science teachers from grades 5 – 12. With such a range of math and science levels, it has become clear that a need exists to develop the curriculum materials and lesson plans to target various grade levels with the ultimate goal of creating an activity that can be considered a k – 12 activity, one that begins in elementary and advances well into high school and beyond.

With rising expectations of students and teachers, it is imperative that new curricula and teacher training programs align with the national standards for math and science. With the breadth and depth of topics covered by microelectronics, it is not difficult to find examples and applications of technology related to the education standards. Topics include copper etching and plating, semiconductors, insulators, conductors, energy conversion, heat transfer, materials properties, dimensions, routing, soldering, circuit symbols, and component types. Each topic ties directly with national standards on math skills and concepts, physical science, science and technology, environmental issues, and science as inquiry. Even more exciting is the natural overlap of math and science topics that will encourage teachers to collaborate and develop integrated lesson plans across disciplines.

Circuit Projects and Procedures

The contents of the circuit building kits are listed in Table 1. Additional supplies required to etch the copper pattern are listed in Table 2. Detailed handouts explaining each of the processing steps are provided in the workshop materials and available from the authors.1 The steps are summarized below:

1. Draw a layout pattern from an electrical schematic.
2. Laser print or photocopy the pattern on the iron-on transfer paper.
3. Clean the copper surface with a Scotchbrite pad, wash in water and dry.
4. Place the pattern face down on the copper.
5. Press firmly with a hot iron for 5 minutes moving every 1-minute.
6. Soak the circuit board in water until the paper floats off the board.
7. Inspect the pattern and repair any missing lines with a permanent marker.
8. Dissolve the etchant salt in water at the proper ratio and preheat to 40-70°C.
9. Etch the patterned circuit boards, rinse with clean water, and dry.
10. Drill holes.
11. Remove remaining toner with acetone.
12. Insert components, clinch, solder, and trim leads.
13. Test, troubleshoot and repair as needed.

<table>
<thead>
<tr>
<th>Table 1. Circuit Building Kit Contents.</th>
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<tbody>
<tr>
<td>Iron</td>
</tr>
<tr>
<td>Scotchbrite pad</td>
</tr>
<tr>
<td>Small soaking tray</td>
</tr>
<tr>
<td>Box</td>
</tr>
<tr>
<td>Hand drill</td>
</tr>
<tr>
<td>Needle nose pliers</td>
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<tr>
<td>Wire cutters</td>
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<td>Wire stripper</td>
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<td>Screwdriver</td>
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<tr>
<td>Multimeter</td>
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<tr>
<td>Soldering iron</td>
</tr>
<tr>
<td>Soldering iron stand</td>
</tr>
<tr>
<td>Solder (2)</td>
</tr>
<tr>
<td>De-solder braid</td>
</tr>
<tr>
<td>Sharpie markers (2)</td>
</tr>
<tr>
<td>Wood board</td>
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<tr>
<td>Drill bits</td>
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<th>Table 2. Additional Etching Supplies.</th>
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<tr>
<td>Press and Peel Wet transfer paper</td>
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<tr>
<td>1 ounce copper printed circuit boards</td>
</tr>
<tr>
<td>Etchant</td>
</tr>
<tr>
<td>Etching dish</td>
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<tr>
<td>Heat source</td>
</tr>
<tr>
<td>Thermometer</td>
</tr>
<tr>
<td>Tweezers or tongs</td>
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<tr>
<td>Components</td>
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</table>

While they may seem unsophisticated when compared to industrial manufacturing methods, the basic steps parallel the steps used in commercial PCB fabrication, serving as a real world example to connect students to the technology. For example, ironing toner onto the copper provides etch resistance like photoresist. The sodium persulfate etchant is a lower concentration of a commercial etching bath, see Figure 1, and hand soldering demonstrates the use of flux and the roles of solder in circuit assembly. The hobbyist approach to circuit board fabrication is easily mastered by all ages and is sufficiently robust to produce successful working circuits. Students and teachers using the process sequence fabricate three primary circuit projects. The simplest circuit has two alternating flashing LEDs driven by a 555 timer circuit. Figure 2 shows the electrical schematic and layout pattern for the flashing LED circuit. The second circuit is a buzzing continuity tester used to find short circuits with a piezoelectric buzzer, two transistors, and discrete components. An electronic dice circuit is the most complicated with several ICs, a 7-segment display, push button, and oscillator.

Figure 1. Circuit boards in etching bath.

Figure 2. Electrical schematic and layout pattern for flashing LED circuit project.
Background of KEEP

Over the past five years, KEEP has progressed from a concept to an activity-based program with teacher workshops. Middle school and high school classes have been lead through the complete circuit building process including pattern transfer, etching, drilling, component placement, soldering and desoldering. These activities were held on-site at each school with all supplies brought in from University of Kentucky (UK). Some classes followed their activity with a fieldtrip to the engineering campus at UK and the Electronic Card Assembly and Test manufacturing line at Lexmark, International. Having built a circuit board by hand, the students were better able to understand the manufacturing steps and appreciate the precision of the automated equipment. Elementary school children have participated in soldering commercially prepared kits with one-on-one assistance from graduate and undergraduate students. While students were taking turns soldering, the class was lead through other activities on static electricity, finding conductive materials using multimeters, and show-and-tell with consumer electronics boards, creating an environment of engaged learning.

Teacher workshops offered in the summers have included 5 – 12 grade science and math teachers. The teachers come to UK from local schools and from the Appalachian counties of eastern Kentucky for a three-day hands-on program. The workshop format rotates among presentations on basic concepts in electricity and electronic materials, individual work on circuit building steps, and team lab activities suitable for classroom demonstrations or labs. Each teacher takes home a circuit building kit of tools and supplies as well as the four working circuits assembled during the workshop. Handouts are also provided on all of the circuit fabrication steps, background on electricity, circuit descriptions, and sample lesson plans with references to the National Science Standards.

Practical Limitations to Implementing KEEP

Teachers and students who complete a workshop or circuit building project have a tremendous sense of pride in having accomplished a unique activity and having a final product, the working circuit, that they may show their friends and families. Feedback comments on the workshops indicate that the format and content are unlike typical professional development courses and that they enjoy the hands-on emphasis over traditional oral presentations. Despite the enthusiasm generated during the workshop, several issues limit the implementation of the KEEP activities in individual classrooms. One issue is teacher confidence to be able to setup and supervise the circuit building steps based on only three days experience and a few handouts. A related issue is teacher isolation within their discipline in their school. For example, a math teacher who has taken the workshop may need access to a chemistry classroom for the etching steps. The practical limitation is having enough kits to supply a classroom. If only one teacher from a school attends the workshop, they will need to purchase several more kits in order to implement the activity in their school. With the workshops offered in the summer, the school budget for the upcoming school year is already designated, so new materials have to wait for the following year, if there is money at all. Finally, the circuit building activity takes several class periods to complete, and the teachers need to be able to justify the expenditure of time and resources on a new program.

Possible Solutions

Teachers who attend the workshop are encouraged to contact Dr. Lumpp for information and assistance in using the materials and kit in their own classrooms. Email and follow-up letters have been sent to encourage teachers to incorporate some of the lesson plans into their school year plans. On-site assistance has also been offered. The informal attempts to assess the program have not spurred significant adoption of the KEEP activities into classrooms. Formal evaluation and assessment are being carried out now in collaborations between Drs. Lumpp and Bradley. In addition, a website will be developed, posting materials affiliated with KEEP so that teachers can access these resources at their convenience. To overcome the limitations to implementation, several approaches are planned.

To address the issues of confidence, isolation, and having enough kits it would be beneficial to offer workshops at individual schools or districts. By training several collocated teachers they could share kits, assist each other in leading the project, and coordinate the circuit building activity as a cross-disciplinary lesson among various classes. Teacher confidence would increase along with the impact on students seeing both the math and science aspects presented collaboratively. In addition, an effort will be made to link teachers across schools and districts via web-based technology, allowing teachers to share experiences.

On-site assistance would also increase teacher confidence and probability for success. Undergraduate and graduate students trained to supervise the circuit fabrication processes are a likely workforce able to accommodate requests from teachers in various locations. Moreover, teachers that had previously participated in the KEEP workshops and implemented the activity in their classroom will be solicited to serve as mentors, building the success of the project and collaboration among teachers.

Providing enough circuit building kits and individual circuit kits requires a moderate level of funding from a school district or grant. To propel KEEP forward through interactions with a few teachers, grant money is being used to supply kits and components as a donation to the school or on loan from UK. Local industry may also be interested in sponsoring the cost of the materials.

Current Implementation Trials

Presently, two science teachers at a local public high school are preparing to teach the KEEP activity in their classes. One will lead 90 sophomores in the physics component of their yearlong chemistry-physics course in the fabrication of continuity testers. The other will lead 60 senior physics students in the fabrication of electronic dice. Both teachers attended the workshop in 2001 and one assisted in
the teaching of the 2002 workshop, giving them the benefits of experience, collaboration, and proximity to UK. They have completed pre-evaluation surveys and will complete post-evaluation surveys after the project. Circuit building kits, circuit boards, components, etchant, and etching tanks have been provided through NSF MRSEC funds. In addition to evaluations from the teachers, student assessments have also been provided including a lesson on calculating the quantity of copper on the circuit board, a student portfolio outline, rubric, and student reflections on the activity.

On-site assistance will be provided as needed; however, one goal of the trial is to determine if the teachers are well enough prepared to implement the project on their own. Another objective of the trial is to determine how to efficiently and effectively use the set of circuit building kits in a classroom. The teachers have the option of distributing the full kits to pairs of students to allow the students to select the proper tools for each step or breaking the kits into stations so that the tools are grouped together for students to rotate from step to step. To date, the kits have been organized for distribution through the workshops. Previous classroom activities lead by Dr. Lumpp have used the same tools; however, the tools were distributed and collected for each step in the process. It will be beneficial to future development of the project to determine optimum design through implementation trials.

Simultaneously, a local private school fifth-grade science teacher is leading 23 students through a partial build project. They have elected to purchase hand drills, soldering irons, and soldering materials similar to those provided in the kits. The circuit boards were etched at UK and components were packaged into an individual set for each student. As a partial build project, the students will drill holes for the component leads, insert components according to the diagrams, and solder. The teacher, who attended the 2002 workshop, will also participate in the pre- and post-evaluation surveys. Through interactions such as these, we will gain valuable insight into the practical use of the KEEP materials for different grade levels.

**Evaluation and Assessment**

In an effort to improve the KEEP program over time and to assist teachers in implementing components of the project, evaluations have been developed and are in the process of being piloted. The evaluations utilize a five-point Likert-type scale, where teachers rate their agreement with various statements. In addition, there are open-ended questions, providing teachers a forum to speak more freely and expand on answers. Before participating in the KEEP training, teachers will be asked to complete a pre-evaluation. This evaluation has three components: current classroom activity, awareness of state and national standards, and time/money factors. This data will serve as baseline data to track connections of the KEEP program with classroom activity over time. Upon completion of the training, teachers will be asked to complete a post-evaluation. This evaluation will be used to encourage teachers to implement the project, asking teachers to set short and long-term goals, and it will be used to improve the KEEP program itself. Finally, three to four months after completing the training, teachers will be asked to complete a follow-up evaluation. This evaluation will address their implementation of the activities and sharing of the project materials with their colleagues. When teachers implement the KEEP activity in their classroom, they will also be asked to complete an evaluation on that implementation, including how they felt the students responded to the project and the ease of implementation. Students are also asked about their experiences with the project as well. To gain a better understanding of the cyclical nature of the evaluation of the KEEP project, see Figure 3.

An effort is also being made to assist teachers in aligning the curriculum and math and science standards with the KEEP activity. To do this, specific lessons have been developed to pull concepts out of the project, for example, measuring surface area; thus, strengthening the link to math and science. Moreover, specific writing assignments have been developed for students to complete at each stage of the project. Within the assignments, the state and national math and science standards are pronounced so that the activity only strengthens the goals set forth by such organizations as NCTM. Specifically, the writing assignments are designed to promote inquiry learning and daily reflection, encouraging students to make their own connections to prior learning and life experiences in both math and science and other disciplines. Upon completion of the project, students are asked to compile a portfolio, placing their best work first and evaluating their own work based upon a rubric that the teacher will use to assess student work. The portfolio allows students ownership of their work, a component of creativity, and an experience of self-assessment. It benefits the teacher by incorporating a performance-based activity within their curriculum, with little planning.

**Conclusions**

Successes with KEEP to date are evidenced in the numbers of students reached through classroom activities, teachers trained in hands-on workshops, and initial development of curriculum materials. Further growth depends on linking activities to education standards, creating valid assessment tools, and supporting teachers in the implementation of the program. In an effort to represent the ongoing evaluation and dissemination of KEEP, a flowchart was created, see Figure 3. It begins with the recruitment of teachers, carrying on to the training process, the continual evaluation process, the implementation of the activity into the classroom, and finally connecting those teachers with previous experience to those newly entering the KEEP program. With the cyclical nature, it is easy to see that the dissemination process could occur rather quickly and continue perpetually.

**Acknowledgments**

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**References**
Teachers complete Post-Evaluation at end of seminar

Teachers are contacted via a Follow-Up Evaluation, encouraging and offering assistance in implementing project into their classroom

Seminar updated based upon teacher feedback

Teacher Participation in KEEP seminar on UK’s campus

Teachers complete Post-Evaluation at end of seminar

Materials made available to teachers via web

Teacher implements activity in their classroom

STARTING POINT

Teachers are mailed information regarding KEEP seminar

Teachers register for training

Teachers complete Pre-Evaluation prior to seminar

Figure 3. Cycle of evaluation and dissemination of KEEP.


