Exploring Traditional and Workbench-Style Kits to Support Project- and Problem-Based Learning

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As project- and problem-based physical prototyping activities become more common in computing and engineering classrooms, it is important to design kits to support desired learning outcomes. The work explored in this paper looks at the effects of organizing physical prototyping materials in individualized (traditional) kits and community (workbench) kits. The findings suggest a correlation in promoting project- or problem-based approaches with organizing materials as traditional or workbench kits.

Keywords—DIY, Making, Kits, Project-Based Learning, Problem-Based Learning

I. INTRODUCTION

The Maker Movement, a do-it-yourself trend that relies on physical prototyping and electronic crafting, has increasingly found its way into classrooms. While the hands-on and project-based nature of these maker activities is an exciting step towards active learning, in engineering and computer science classrooms it is important to consider the nuances of these activities and how they are situated to improve learning [1]. This study seeks to understand how the organization of materials into maker kits support these activities in different ways. Additionally, we explore the relationship between the presentation of these kits and the intended learning outcomes of these activities. As instructors work to guide students through project- and problem-based learning exercises, toolkits must be modified to provide appropriate constraints and create a satisfying learning experience for students. In this work, we build on principles of convergent and divergent thinking as it relates to hands-on activities and propose how instructors can successfully tailor kits of tools and materials. Furthermore, we explore how tailoring these kits can help students successfully explore a variety of possibilities (divergence) or narrow the scope of their work (convergence) and will discuss these ideas from the perspective of project- and problem-based learning. This study is focused on undergraduate computer science classrooms, but the findings may inform maker learning activities in K-12, informal learning and other engineering disciplines.

II. BACKGROUND

This work primarily draws from two areas of work that are becoming prominent topics when considering the evolution of undergraduate computer science curricula. These areas include the rising importance of physical prototyping and supporting toolkits, and the role of project- and problem-based learning activities. It is at the intersection of these topics that we have found a relationship that allows instructors to consider the nature of their activities and adjust the way in which tools and materials are presented to help scaffold desired learning outcomes.

A. Kits

As hands-on building activities find their way into traditional computer science and engineering curriculum through physical computing, ubiquitous computing and prototyping classes, kits have become a common way to support the demands of providing tools and materials to students [3]. With in these context, *Kits* are a thoughtful and organized collection of items that support a specific hands on making activity.

A common approach to supplying these kits is to create or purchase kits that contain an identical number and variety of components to be distributed to individual students or groups. The Sparkfun Inventor's Kit, for example, contains simple electronic components that allow students to work through 16 different exercises to learn basic electronic programming and physical prototyping skills. While the scope of this kit is rather broad, others have created kits to narrow on specific topics such as wearable computing, e.g. LillyPad Arduino kits [4]. The appeal of such kits often comes from their relative accessibility to students that are new to prototyping and their pre-packaged format. In this work, we will consider such standardized collections of tools and materials to be *traditional kits*. These traditional kits are characterized by an individual container for each student or group that has all the required tools and materials for the activity.

Beyond traditional kits, however, there exist other approaches for supplying tools and materials to students that can often reshape their learning experience and produce alternative outcomes. For example, in Perner-Wilson's "kit of no parts," students expand their conceptual knowledge of electronics by using available crafting materials to create

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simple sensors [10]. This alternative approach has the potential to augment students' understanding of components beyond a traditional kit in some circumstances. Another approach, commonly used in supplying tools and materials to students, involves pooling all of the class resources into categorized bins that allow students to explore, select and share components throughout the entire space. This *workbench kit*, so named because it resembles a workspace where tools and materials are communally available, contrasts from the traditional kit insomuch that students must now make choices with respect to a wider variety of components to choose from. Using this approach may also help students as they transition from in-class activities to independent out-of-class activities in a prototyping lab or workshop space.

Traditional and workbench kits can facilitate learning opportunities for students, and can make classroom instruction easier for instructors if designed well (Figure 1). In this paper we suggest a number of considerations in designing kits by considering the desired learning outcomes of the classroom activities.

B. Project- and Problem-Based Learning

The structure of Problem-based Learning (PBL) as a scaffold for Project-based Learning (PrBL) outlined by Barron et. al. (1998) can serve as a framework for learning structures that can be provided with kits that scaffold workbench making [2]. In Learning by Design (LBD) many of these same ideas are put forth, but with a focus on a structured iterative process. We seek to briefly identify critical pieces of PBL, PrBL and LBD to serve as a foundation for interpreting our experience with designing kits.

In PBL, learners are presented with a problem to solve. This problem should activate prior knowledge and allow for the learners to build upon this knowledge by working in small collaborative groups. The groups work together to construct a model to explain a problem then to test these models. As the learners test these models, they develop new understandings and uncover new questions. This triggers the same process, where learners try to understand the new problem by building and testing models [11]. Barron et. al. explored PBL in relationship to PrBL. In these structures PBL served as entry points to projects, scaffolding student learning so they understood how to develop models, test, iterate and revisit a project within the constraints of a specific problem. In PrBL, students are introduced to projects that they are able to work on over a greater period of time than PBL [2]. This problem would be an open-ended real-world problem that involves complex task that offer students the opportunity to collaboratively work toward an authentic end product or presentation [5]. A challenge with PrBL is that students can flounder without appropriate scaffolding and the advantage of implementing the PBL first is that it provides students with some experience in solving related open-ended projects.

Figure 1. Comparison of a traditional kit (top) and a workbench kit (bottom). Each has similar components but are assembled and presented differently to students based on the desired learning outcomes of an activity.

In LBD a more structured approach to learning with design is outlined. This typically involves a sequence of activities that focus on an initial design challenge using only prior knowledge, a whole class discussion to share ideas, identifying additional knowledge needed to move forward to improve the design, and ongoing iterative step to address issue that students need to learn to improve their design. This often involves similar pedagogical process to a design studio course with students doing experimental work interspersed with walk-throughs talking about students designs and more informal pin-ups where students share ideas, questions that allow for reflection of the learning process, and the generation of additional issues [6].

C. Convergent and Divergent Thinking

One of the desired outcomes of implementing hands on activities in computer science and engineering classrooms is to help students understand the how to engage in convergent and divergent thinking. During convergent thinking, students often times have a well-defined problem for which they are working to find a unified solution [8]. Because of this, such thinking is advantageous when engaging in PBL. Similarly, during divergent thinking exercises, students are encouraged to consider a wide variety of possibilities and often times question the underlying assumptions of the problem itself[8]. This process inevitably results in a more project-based approach and thus fits the model of PrBL well. Because of this relationship, instructors can consider both the type of thinking required for their activities and match them to a respective learning approach

III. METHODS

In order to understand how the construction and presentation of tools and materials in a variety of kit formats would affect student outcomes, we developed two activities that had distinct desired learning outcomes. Using a design-based research approach allowed us to iteratively explore the constraints introduced by these kits and to tailor these activities to a variety of classrooms. These activities were pilot tested during an undergraduate section of mobile and ubiquitous computing, with the understanding that such activities would help students in their semester-long projects to develop an interactive prototype (Table 1). This classroom format allowed us to test kits that were meant to facilitate shorter problem-based activities (PBL) as well as the long-term project-based assignment (PrBL). Based on that experience, we deployed these activities in additional classes including a graduate level user interface development class and an undergraduate prototyping class. Deploying the activities in multiple classes with different expertise levels and allowed us observe the combinations of activity types and kits (e.g. problem-based activities with traditional and workbench kit) under multiple conditions. While these additional courses vary by topic, each has an element that introduces students to building physical prototypes. Data was collected through semi-structured interviews conducted with students at the end of the semester, direct observation by the researchers during the activities, as well as feedback from course instructors attending the sessions.

A. In-Class Maker Activities

To explore the variety of ways in which tools and materials could be provided to students, we created an activity that was grounded in a problem-based scenario and another that engaged students with a project-based approach. These relatively simple activities each included a small amount of introduction and instruction, followed by a period of time for students to complete a design challenge and present their work to the class.

1) Manual Prototyping (Problem-Based Activity)

Manual prototyping plays a key role in the development of ideas. In this problem-based activity, students were presented with the problem of creating an interactive lamp prototype from a selection of prototyping tools and materials. Our desired outcome was to help students learn methods of creating simple prototypes while also focusing on solving a problem as a group when given limited resources.

We introduced students the principles of manual prototyping, i.e. creating prototypes by hand using inexpensive materials that are easily manipulated. Next we conducted a demonstration of two types of materials that many had not experienced before. The first, foam core, is a foam and paper laminate that is easily cut and glued to create rigid structures. The second, InstaMorph, is a moldable plastic that becomes soft when heated and rigid when cooled. After seeing the properties of each material, students gathered into small groups to begin sketching and discussing ideas of how they could use these materials to create a simple prototype of an interactive lamp (the lamp itself would not be functional, but students were to use the manual prototype to convey the idea of interactivity). After a short period of brainstorming, groups were then given access to foam core sheets, InstaMorph pellets. X-Acto knives, scissors, hot glue guns, rulers and protractors to begin their prototyping. After 30 minutes of prototyping, students were then given the opportunity to briefly share and explain their interactive lamps to the rest of the class.

2) Wearable Prototyping (Project-Based Activity)

Developing technology that can be worn on the body presents a number of challenges and opens up a wide variety of possible designs. In this project-based activity, we introduced students to a set of five design considerations to consider when creating a prototype that is worn on the body. These design considerations included where to position the device on the body, the weight of the device, how comfortable it is, how well it supports natural movement, and its overall size. The desired outcome for this activity was to encourage students to explore a variety of approaches to developing wearable prototypes while considering the physical limitations inherent to such devices.

Student groups were assigned a general region of the body (torso, neck/head, legs/feet, arms/hands) and engaged in

TABLE I. Summary of Activities Conducted with Traditional- and Workbench-style Kits

Course Type	**Class Size**	**Activity**	**Activity Type**	**Kit Type**	**Data Collection**
Mobile and Ubiquitous Computing	35	Manual Prototyping	Problem-Based	Traditional Kit	Semi-Structured Interviews with nine students, observation, instructor feedback
Mobile and Ubiquitous Computing	35	Wearable Prototyping	Project-Based	Workbench Kit	Semi-Structured Interviews with nine students, observation, instructor feedback
Introduction to Prototyping	18	Manual Prototyping	Problem-Based	Workbench Kit	Researcher Observation
Introduction to Prototyping	18	Wearable Prototyping	Project-Based	Traditional Kit	Researcher Observation
User Interface Design	55	Manual Prototyping	Problem-Based	Traditional Kit	Researcher Observation, Instructor Feedback
Prototyping Interactive Systems*	24	Manual Prototyping	Problem-Based	Workbench Kit	Researcher Observation, Instructor Feedback

**Indicates a graduate level class.*

sketching and discussion. Again, after a brief period of brainstorming, they were given 30 minutes to create a physical prototype for their part of the body using the provided materials. In this activity, they were provided with foam core, moldable plastic pellets, X-Acto knives, scissors, hot glue guns, rulers, Velcro strips, a variety of tape, dense foam blocks, hot wire foam cutters, and fishing weights. Students then presented their work and discussed how their prototypes conformed to the five design considerations and tested their prototypes on fellow students.

B. Student Interviews, Researcher Observations and Instructor Feedback

Data was collected through semi-structured interviews with students at the end of the semester, researcher observations during the activities, and instructor feedback gathered after each activity. This approach allowed us to look at both how students and instructors perceived the effects of various kit methods on the specific activities presented, as well as observing emerging behaviors during the activities.

1) Student Interviews

As part of a larger study on implementing maker activities in undergraduate courses, we conducted semi-structured interviews with nine students at the completion of the mobile and ubiquitous computing course. Topics covered during these interviews included the overall student experience during the course, if the in-class activities affected their out-of-class work, their feelings toward the in-class activities and the different ways in which materials and tools were provided to them, as well as their feelings toward the Sparkfun Inventor's Kits that were provided to them as part of the class materials. Interviews were audio recorded, transcribed and then analyzed to identify common themes in the interviews. We then coded the interviews and extracted the most salient points by choosing codes that had a high occurrence among the individual analyses.

2) Researcher Observations

While students worked in class on the prototyping activities, we observed groups by taking notes, photos and video recording the sessions. This allowed us to freely observe groups while they were working on their activities and see what they were designing and how they were going about designing it. During these sessions, we were interested in the dynamics of the group members during the prototyping exercises, the use of appropriate materials and tools used in the design of the prototypes, and the finished prototypes at the end of the sessions.

Upon completion of each activity, groups were allowed to present their prototypes to the class, allowing the researchers an opportunity to evaluate how well students were able to complete the activity. During this time, it was possible to assess how well students used the tools and materials provided through the traditional and workbench kits. This assessment was unique to each activity based on the learning outcomes for the students. For example, in the manual prototyping activity we hoped to see students experimenting with both of the new prototyping materials, whereas in the wearable technology activity we hoped to see students use good judgment when selecting materials that fit the design considerations when constructing their prototypes.

3) Instructor Feedback

We also solicited feedback from instructors and teaching assistants of the classes after each prototyping activity. This feedback centered on the effectiveness of the activities in meeting learning goals, as well as the feasibility of implementing the various kit styles, and the effect of in-class prototyping activities on out-of-class projects.

As students transitioned from working on these introductory in-class prototyping activities, we were interested to see how instructors perceived students' utilization of campus resources for their out-of-class activities. This was important because many of the available campus resources, such as prototyping labs and workshop spaces have been organized using a workbench kit style of distribution, with tools and materials being grouped as a shared resource as opposed to individualized traditional kits. The desire was that by introducing students to this alternative style of kit that we would be able to alleviate confusion when transitioning from one method of prototyping kits to another.

IV. FINDINGS AND DISCUSSION

As we compiled our data from the student interviews, researcher observations, and instructor feedback, a few strong themes emerged that shaped our ideas in regard to correlating problem- and project-based activities with traditional- and workbench-style kits.

A. Initial Findings

Within the traditional kit approach we found elements that functioned as useful constraints and scaffolding, while the workbench kits provided creative flexibility. Furthermore, we saw evidence of how groups function differently when presented with tools and materials in various kit formats.

1) Varying Constraints of Kits

When presented with a traditional kit, many students found the constraints of the limited tools and materials to be useful during the problem-based activities (PBL) that focused on introducing them to unfamiliar materials and prototyping methods. When asked to reflect on using the traditional kit during these activities, students responded with comments such as, "the [activities] where everybody was doing the same thing, the tool box was a lot easier." Another went on to explain that in these circumstances, they felt that "we need to build something out of this, so we have to come up with something with what we have because there's nothing else." Furthermore, the researchers and instructors observed a satisfactory mastery of the materials during these exercises.

In contrast, however, students found that the workbench kits to provide an adequate amount of flexibility during the project-based activities (PrBL) because it allowed them to be more creative. “If you needed something different, you had to think on the fly,” commented one student. “I think I’d rather come up with an idea and then go find the tools, because you generally come up with a more interesting idea.” From the instructor’s perspective, this approach was successful as well. This was evident in that students demonstrated the ability to master techniques during the problem-based activities with traditional kits, albeit with little variety between prototypes, whereas students showed a larger spectrum of creativity during the project-based activities with workbench kits.

2) Divergent versus Convergent Prototyping

We found that the certain combinations of activities and kits could help foster divergent or convergent thinking among the student groups. During project-based exercises with workbench kits, we observed many student groups prototyping divergently, developing multiple prototypes simultaneously, using the variety of materials available and rapidly comparing and contrasting ideas. Interviews supported these findings as one student recalled when reflecting on a workbench supported project, “We created two prototypes in parallel out of the plastic moldable material and one out of foam board and the good thing about doing that was when it was done, we had one that worked because the other one was just horrible.”

In contrast, when using traditional kits, students felt pressure to make use of all the components in the kit in their design. “If we’re going to build this with these [materials], what would we do?” was the motivation behind one group’s approach to prototyping during this activity. This approach was similar to convergent thinking in that convergent thinking patterns were frequently observed as students worked to incorporate all the components of their traditional kit.

3) Influencing Roles within Groups

During the development of these activities, the initial design did not consider how each kit would affect the roles of students within their groups, but both researcher observations and instructor feedback called attention to how the varying types of kits can influence teamwork. The traditional kit generated opportunities for students to establish a quick division of labor, which we found to be linked to the limited number of tools and materials provided to individual groups. For example, a traditional kit for four students that has two X-Acto knives and two hot glue guns, encouraged students to divide labor among group members based on these tools, i.e. two would cut pieces, while two would glue them together. During the times when workbench kits were used, however, a different dynamic was observed. Instead of division of labor between tool and material-oriented tasks, it was more commonly observed that students would organize themselves by tasks. For example, one student might use several tools to complete one part of the project, while another works on a separate part with the intention of combining them later.

B. *Choosing Appropriate Kit Styles*

Based on these findings, we have explored a relationship between kit styles and desired learning outcomes. By thoughtfully designing kits with learning goals in mind, we were able to help shape the student experience and learning outcomes. Furthermore, the experience of testing these various implementations has led to additional insights when working within the constraints of traditional classroom spaces, as well as some practical considerations to make when adapting these activities. When planning hands-on prototyping activities, it is appropriate to consider how the presentation of the materials and tools will affect the student experience.

As such, in our implementation of various strategies, we have concluded that problem-based activities are generally better supported by traditional kits, whereas workbench kits are preferred when implementing project-based activities.

1) Manual Prototyping and Problem-Based Activities

The affordances provided by a personalized collection of materials provided by traditional kits, creates a low-risk experience in which students are able to focus on solving the problem on hand. This is particularly the case when considering how providing a well thought out selection of tools and materials can assist in scaffolding students’ learning when presenting them with a new or unfamiliar task. The inherent properties of the items in the traditional kit can serve to prompt students to use them in a way to is appropriately constrained.

Furthermore, we observed that controlling the number of available tools and materials in these kits can help create natural roles and division of labor among student group members and created a natural dialog among the students as they worked together to create the prototype. This approach also facilitated convergent thinking among student groups as they worked to narrow the scope of their work to what had been presented to them in the traditional kit. This approach may help overcome some of the traditional scoping problems inherent to introducing problem-based activities into computer science curriculum [9]. There may also be a risk that students division of labor leads to uneven learning in groups, with each members becoming a more expert contributor in one aspect rather than a holistic learning approach. In designing PBL activities with traditional kits, creating moments for students to switch off task or to conduct peer to peer instruction might mitigate this risk.

When presented as a workbench kit, however, the loose structure of providing tools and materials to students seemed to hinder, rather than help, the desired outcome in PBL. This is true when considering how students made decisions about which materials to use. Students would often focus on one type of material when presented to them in the workbench kit, despite the desire to see students become familiar with all of the materials. In this way the workbench in problem based approaches, rather than opening the design space, limited the exploration that students took with the problem.

2) Wearable Prototyping and Project-Based Activities

In the case of project-based activities such as the wearable technology prototyping, students were better able to meet the desired learning objectives when presented with a workbench kit rather than a traditional kit. The exploratory structure of having materials organized this way allowed students to leverage divergent ways of utilizing the materials in their prototypes and resulted in a greater variety of prototypes. This method also promoted appropriate incorporation of materials into projects as students were less compelled to use every single type of material. It is important to notice the difference in learning outcomes in this activity when compared to the manual prototyping activity. Whereas in the manual prototyping activity, students should become familiar with new materials, in this activity, the desire is for students to use solve complex problems through known methods and materials per PrBL [5].

One additional aspect of this approach is how materials can become scarce because they are a community resource. We were pleased to see this result in two distinct behaviors during the prototyping sessions. First, it prompted some students to communicate with other groups to share their materials and sometimes even conserve their material usage. Second, a number of off-label uses emerged for materials, such as using doubled-over pieces of duct tape as chest straps when the source of Velcro straps had depleted. This divergent use of materials was especially encouraging because it helps students overcome the notion of single-purpose tools and materials [7].

One difficulty in presenting an activity of this type, where the goal is prototyping in a traditional kit format, was apparent in the relatively homogenous approaches students took in using the materials. Another limitation of this approach was being able to supply every traditional kit with a wide variety of materials and especially tools. It seemed wasteful and expensive to outfit every kit with samples of every material and duplicates of expensive tools. Furthermore, it was difficult to anticipate the quantity of materials to provide in each kit, as some groups would use much more of one resource than others.

C. Classroom Considerations

A result of exploring how kits affect in-class prototyping activities was discovering a number of considerations to make. Through implementing these activities in both traditional and flexible classroom spaces, we have found that there are a few recommended features that allow these activities to work better. In terms of traditional classroom spaces, we have conducted these activities in spaces that include both individual desks and fixed, unmovable tables. While both have their fair share of limitations with respect to hosting any type of prototyping activity, we observed that fixed tables can prove troublesome when working with the workbench kits because the physical layout of such spaces can restrict the movement necessary to facilitate this approach.

Our experience with flexible classrooms has been encouraging. These classrooms include rolling tables, making group organization easy, as well as providing accommodations for both traditional kits and workbench kits. These spaces include access to power through many wall- or floor-mounted electrical outlets, as well as multiple projection surfaces to allow groups to orient in many directions and still have easy access to the presentation materials.

We have also observed a number of tradeoffs between these two kit approaches as class size increases. The usual class size in which we have conducted these activities ranges between 25-35 students. In this range, both approaches work well. Beyond that, however, there are significant advantages and disadvantages to each. From a classroom management perspective, traditional kits limit the need for mass movement, whereas the workbench kit often results in a stampede of students vying for materials. This tradeoff unfortunately places the burden of creating and resupplying traditional individualized kits for a large number of groups, whereas the workbench kits are easy to monitor and resupply as necessary. Nevertheless, we have successfully implemented both approaches with large classes (around 60 or more students), but careful consideration is encouraged before committing to one approach.

V. CONCLUSION

As a result of this work, we find strong reasons to conclude that problem-based activities in the classroom can be best supported by traditional kits, whereas project-based activities are best supported by workbench kits. Our exploration of this has discovered a variety of ways in which these kits can properly guide students' learning, as well as helping them converge and diverge when appropriate. Furthermore, we have discussed a number of practical considerations that are useful when implementing such activities and kits into classrooms.

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