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Use of Individual Lab Kits to Enhance Hands-on Learning in Electronic Circuits Courses

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Abstract

The Electrical and Computer Engineering Technology degree program at Western Carolina University offers a series of lab-lecture courses covering DC circuits, electronic circuits with active devices such as diodes and transistors, and AC circuits. These four credit hour courses include one laboratory session per week. During the COVID-19 era, these classes were offered remotely using lab kits consisting of an all-in-one pocket-sized data acquisition module, a breadboard, and a set of passive and active electronic components. While using these kits for remote instruction, the authors found that they offered key advantages that would benefit traditional in-person instruction. First, lab kits overcome the equipment and space limitations of traditional laboratories and allow all students to effectively have a personal lab bench. Prior to COVID-19, laboratory exercises were frequently completed with a lab partner; however, there are basic laboratory skills, such as circuit breadboarding, that students must master individually. Individual lab kits enable each student to have the same learning opportunity and master these critical skills. Second, the portability of lab kits allows students to work on laboratory exercises remotely. This might be necessary if a student was unable to complete lab exercises during allotted classroom time and promotes inclusion for students with learning accommodations. It is also helpful for students with excused absences stemming from health-related issues or extracurricular activities (athletics, band, etc.). Rather than holding an extra lab session, students can complete the lab at their convenience. Remote laboratory capability also opens the opportunity for post-lab and homework exercises that blend theory with physical application. Third, the pocket-sized data acquisition module provides students with similar capability, and in some cases enhanced features, compared to a standard electronics test bench with power supply, digital multimeter, oscilloscope, and function generator. The enhanced functionality of the pocket device can be used to develop more engaging laboratory activities. Lastly, individual lab kits provide students with the opportunity to engage in self-directed learning outside of course-related assignments.

For these reasons, the authors have continued to use lab kits originally designed for remote instruction even after returning to in-person courses. Individually issued lab kits are used in conjunction with traditional benchtop equipment both in class, during regular lab sessions, and outside of class. This paper presents the results of incorporating lab kits into in-person electronic circuits courses. Through student perception surveys of lab kits and benchtop lab equipment, as well as individual and group lab assignments, the authors discovered that (1) students are comfortable with both individual lab kits and benchtop equipment and view these two resources as complementary, (2) students see value in individually-completed labs but also like the peer-to-peer mentoring that can occur when working with a lab partner, and (3) students are using lab kits outside of class for a variety of activities, including self-directed learning. Disadvantages and limitations of lab kits are also reviewed and discussed.

1. Introduction

Individual lab kits have been evaluated as a tool to enhance active learning, even before the pandemic [1], and many types of lab kits have been designed for specific courses [2] [3] [4]. The pandemic pushed many educators and students to start using individual lab kits [5] [6], greatly expanding their utilization. The educational community continues to explore and experiment with individual lab kits to find new ways to use them even after the pandemic [7] [8]. Besides regular classrooms, individual lab kits can also be used in resource-scarce environments such as refugee camps [9], which has helped some refugees stay engaged with learning despite their challenging living conditions. The most popular electronic lab kit devices include the Analog Devices ADALM2000 (simplified as M2K) [10] and Digilent Analog Discovery 2 (simplified as AD2) [11], which are compared in [4]. As described below, the authors have used the M2K device in circuits courses to complement the traditional lab experience in the post-pandemic era.

The B.S. Electrical and Computer Engineering Technology (ECET) degree is a residential program at Western Carolina University. The circuits sequence consists of three courses summarized below. Each course is 4 credit hours and combines lecture and lab. Prior to COVID-19, these courses utilized traditional in-person labs with standard benchtop equipment (multimeter, power supply, oscilloscope, and signal generator). In most cases, students completed labs with a lab partner.

Circuit Analysis I
Fundamental electrical theory involving DC circuits. Topics include series, parallel, and series-parallel networks; methods of circuit analysis and network theorems; electrical instrumentation and computer analysis tools used in performing laboratory experiments. Credits: 4. Contact Hours: 3 Lecture, 2 Lab.

Electronic Circuits
Study of analog electronic circuits including amplifiers, regulators, and special applications. Both discrete semiconductor devices and integrated circuits are covered. Credits: 4. Contact Hours: 3 Lecture, 2 Lab.

Circuit Analysis II
Fundamentals of DC/AC circuits. Topics include AC series, parallel, series-parallel circuits; analysis techniques; network theorems; resonance, and transformers. Credits: 4. Contact Hours: 3 Lecture, 2 Lab.

As a result of COVID-19, these courses were offered in hybrid or online modalities during the 2020-21 academic year. To provide hands-on lab exercises during this period, students were provided with individual lab kits for remote use. The lab kit primarily consisted of the Analog Devices ADALM2000 (M2K) multifunction instrument with coax adapter board, a parts kit consisting of electrical components and a breadboard, and coax cables. The students were required to purchase a handheld multimeter for use in some of these courses. Under these circumstances, lab kits proved to be an effective tool for hands-on learning.

With the pandemic subsiding, pedagogies developed for remote instruction are being used to supplement in-person learning. The authors believe that portable lab kits complement traditional benchtop lab equipment by providing opportunities for learning outside of the classroom, and individualized learning experiences inside the classroom. Furthermore, lab kits can alleviate the space and equipment limitations of traditional electronics labs outfitted with lab benches and benchtop equipment. Starting with the 2021-22 academic year, students in ECET circuits courses were issued a lab kit for use in lab exercises (in-class, and out-of-class) and homework exercises. This paper surveys student opinion on the use of individual lab kits to supplement traditional, in-person instruction.

2. Research Objective

The pandemic has pushed many educators and students out of their comfort zone, which has also created opportunities to explore new approaches to enhancing student learning. During this period, the authors specifically explored the use of individual lab kits in circuits courses and found them capable of handling most, if not all, circuits labs while being convenient and portable. Therefore, even after the pandemic, the authors have continued to incorporate individual lab kits into course offerings, not as a replacement for traditional benchtop equipment, but as a complementary tool that expands learning opportunities beyond scheduled class time. For in-person labs, students have used both styles of equipment (lab kit and benchtop equipment). Students were also given assignments outside of class that used the lab kit. Some of these assignments complemented in-person lab exercises (and were called “post-lab” exercises), and other assignments were essentially homework lab exercises. The primary objectives of this work are to:

- document the actual use of lab kits inside and outside of class,
- assess student perception of the use of lab kits and determine whether there is a preference for lab kits or benchtop equipment, and
- assess student perception of working individually or with a lab partner for in-person lab exercises.

3. Methodology

A new pilot survey was developed to assess student use and perception of individually-issued lab kits containing a pocket-style multifunction device (M2K). Students that started the ECET circuits sequence during or after the 2021-22 academic year were invited to participate in the survey. To be eligible, they must have successfully completed at least one of the three ECET circuits courses and continue to be enrolled in the ECET degree program at Western Carolina University. This ensures that students have primarily used their individual lab kits as part of in-person courses, rather than online courses. Students prior to the 2021-22 academic year would have used their kits as part of remote courses, and not had access to traditional benchtop equipment, both of which might affect their perceptions of individual lab kits.

The survey catalogued the types of activities that the student had engaged in with the M2K (lab exercises, post-lab exercises, homework, projects both personal and for other classes). The M2K does require installation and setup which is not required for benchtop devices, so the <u>ease of setup</u> was surveyed with a three-level Likert scale (easy, challenging, impossible). The <u>ease of</u>

use was surveyed for both the pocket device and benchtop equipment using the same scale. Lastly, students were directly asked which equipment they preferred for lab exercises (M2K only, benchtop equipment only, combination of M2K and benchtop equipment, either-doesn't really matter).

The students were also asked about their perception of learning and engagement when completing labs individually or with a lab partner. Using a standard 5-level Likert scale, students were asked to indicate their level of agreement with the following statements:

- Performing laboratory exercises on an individual basis helps me learn hands-on circuit building and testing skills.
- Performing laboratory exercises with a lab partner helps me learn hands-on circuit building and testing skills.
- Performing laboratory exercises on an individual basis helps keep me engaged throughout the lab.
- Performing laboratory exercises with a lab partner helps keeps me engaged throughout the lab.

Lastly, students were directly asked which format they preferred for lab exercises (individually, with a lab partner, sometimes individually and sometimes with a lab partner, either-doesn't really matter).

The pilot survey was distributed electronically through Qualtrics, and participation was strictly optional. 22 of 34 eligible ECET students voluntarily participated in the survey. The overall student response rate (65%) was reasonably good and can be attributed to generally positive student-faculty relations. The sample size for this study is small due to the ECET cohort size (10-20 students) and the limited number of academic years since returning to in-person instruction after COVID-19. In future academic years, additional data will be collected using this survey instrument to increase sample size and assess student perception over time.

4. Data and Analysis

Summary Data

Figure 1 shows the courses that have been completed by the survey respondents. 82% of students have completed Circuit Analysis I, the first course in the circuits sequence; however, transfer students, or students in other special circumstances, might have taken a similar course elsewhere. Of the respondents, 50% have taken at least one of the later courses in the sequence. Again, for various reasons, students might be out of sequence, or received transfer credit for some of these courses. Since each course utilizes the M2K in different ways, it would have been interesting to group the responses by course(s) taken; however, the sample size was already small so all responses were considered as a single group regardless of course(s) taken.

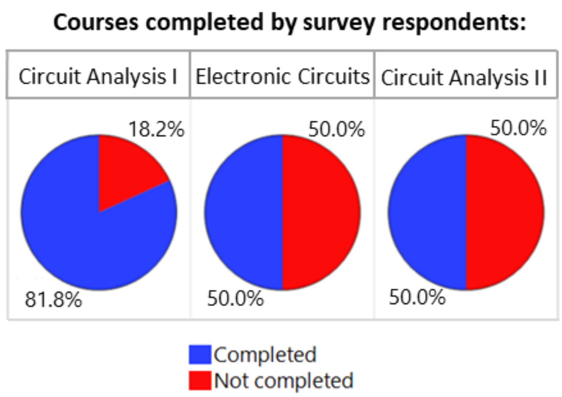

Figure 1. Circuits courses completed by survey respondents.

Table 1 shows the types of activities for which students reported using the M2K. From this data, it is clear that the M2K is a valuable tool for completing in-class lab activities outside of class due to inadequate time (100%) or absence (55%). Not all courses require post-lab exercises, so only some of the respondents reported this activity (86%). Likewise, some of the courses (mainly Electronic Circuits) have lab exercises associated with HW assignments, so the percentage of students reporting this activity (54%) closely mirrors the percentage that have taken this course (50%).

Perhaps the most interesting data relates to uses that are not associated with the circuits course sequence. 36% reported using the device on personal projects which indicates that the M2K can be an important enabler for self-directed learning. 27% used the M2K to complete a project for another class. Again, the M2K provided a capability that would have been otherwise unavailable except through on-campus labs during standard work hours (M-F 8am-6pm). Interestingly, 73% of students used the M2K to provide capability that is not available with standard benchtop equipment (multimeter, power supply, signal generator, oscilloscope). So despite being a compact, pocket-sized device, it is in some respects more capable than a traditional benchtop setup.

Table 1. Percentage of students that used M2K for various activities (n=22)

Activity	**Count**	**Percentage**
Complete lab exercises in class	22	100%
Complete lab exercises outside of class that I did not finish in class	22	100%
Complete lab exercises outside of class due to an absence (excused or unexcused)	12	55%
Complete additional required lab exercises outside of class ("post-lab" exercises)	19	86%
Complete HW assignments	12	55%
Work on a personal project (non-class related activities)	8	36%
Work on a project for another class	6	27%
Provide measurement and test capabilities not available through standard desktop equipment (multimeter, power supply, function generator, oscilloscope)	16	73%
Other	4	18%

Student Perception of M2K

Figure 2 shows student perception of M2K setup difficulty and comparison of ease-of-use for the M2K and benchtop equipment. The vast majority of students (86%) indicated that the M2K was easy to setup and use while 14% reported that it was challenging. None reported that the M2K was impossible to setup or use. Students also thought that the benchtop equipment was easy to use (73%), albeit at a slightly lower rate.

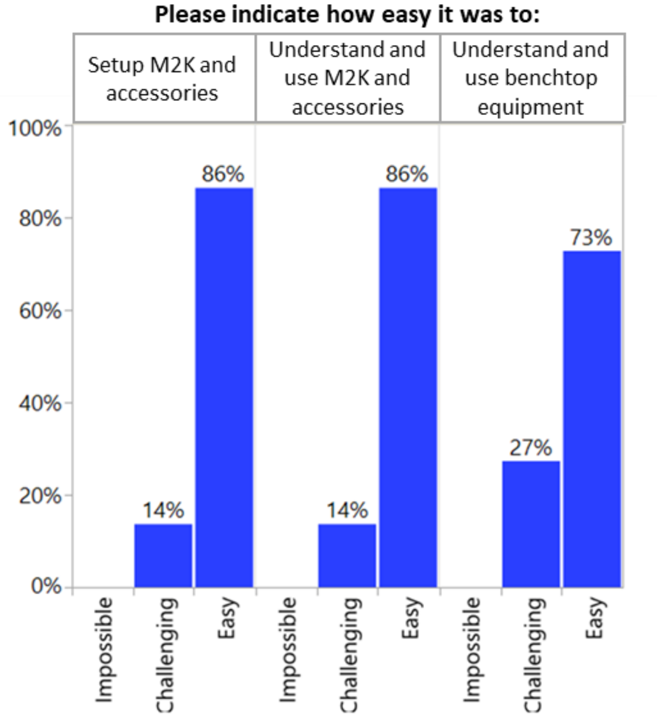

Figure 2. Student perception of M2K setup difficulty and comparison of ease-of-use for M2K and benchtop equipment.

Student equipment preference for in-class lab exercises is shown in Figure 3. 73% of students see the M2K and benchtop equipment as complementary, and would prefer to use both during lab exercises, presumably to take advantage of each option's strengths. No students indicated a preference for exclusively using the M2K, while 9.1% would prefer to only use benchtop equipment. 18% did not have a strong opinion and could use either.

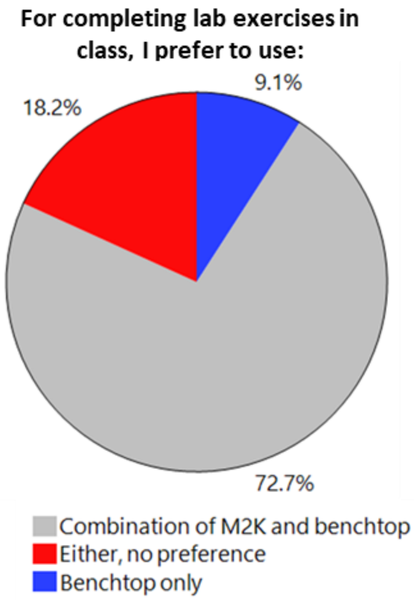

Figure 3. Student equipment preference for in-class lab exercises: M2K only, benchtop only, combination of M2K and benchtop, either-no preference.

Table 2 provides selected student comments related to what they liked and did not like about the M2K and benchtop equipment. The number of students making similar comments is also included in the table. Four students specifically mentioned the ability to work remotely to complete lab exercises that they were not able to complete in class. Students also liked the M2K functionality, and specifically the ability to export data directly to their PC. Some M2K disadvantages noted by students included: device reliability (M2K software stability), difficulty managing many connections with the cables provided, need to bring another device to class, and limitations associated with student's personal laptop (which is used to control the M2K). There are certainly cases in which the student's laptop is not working properly, and this impedes their ability to use the M2K effectively.

Table 3 summarizes student comments when directly asked about their preference between the two types of equipment. The number of students making similar comments is also included in the table. The majority of these comments reflected the value of learning both types of equipment to take advantage of their strengths. Several students noted that the measurement performance of benchtop equipment is superior and preferred it for that reason.

Table 2. Summary of selected student comments on M2K and benchtop equipment grouped by category of response. Number of students providing similar comments is noted.

Category	**Selected Student Comments**	**# of Students**
M2K: Ease of Use	• compact and easy to use • portable and connected to my computer directly • easy to use and reliable	7
M2K: Accessibility	• Sometimes there's not enough time ..., so having a resource like M2K that you can work on at home was really helpful for me. • I like the accessibility of using the device at home if I need to finish a lab. • it does make it easier to work on labs from home	4
M2K: Functionality	• easy [to supply] power to a … breadboard • easier to export data • lots of functionality • It's great to have many types of measuring and utility devices (multimeter, power supply, etc.) in one device that's easy to setup…	4
M2K: Disadvantages	• This device is not reliable as it rarely gives the correct voltage/current values. This could be due to incorrect calibration but most classmates have problems regularly. The interface is also not as user friendly because the cable are so stiff the board cannot sit upright and there are so many cables that it is impossible to not get everything tangled up will always be unorganized. • It's easy if I don't have to bring m2k to class. My laptop has a small screen. It's nice to have all the data displayed elsewhere. • M2K gets a little cluttered for me when building a circuit and measuring values. • Scopy software is kinda weird to use because you have to activate multiple parts of the software for one to work.	4
Benchtop: Ease of Use	• It's always set up • user friendly • I like how straight forward the equipment is to use and how easy it was to understand. • I feel like I can set up the benchtop equipment easier and be able to know what is wrong if I have any problems. • easy to access metrics makes it easier to provide accurate results for lab tables and graphs • I like it because it is simple to find everything while using the equipment.	10
Benchtop: Functionality	• These are much more reliable. • All the equipment is separated, providing more room to work in. Using the M2K just felt a little cramped given its size and required distance to a computer. • accurate	5
Benchtop: Other	• It's also good to have a basic understanding on how to use benchtop equipment in case I don't have the M2K. • It's the critical equipment of the industry that I am studying to get into. Please don't remove the bench top equipment until after I graduate.	1

Table 3. Summary of selected student comments on student preference between the M2K and benchtop equipment. Number of students providing similar comments is noted.

Category	Selected Student Comments	# of Students
M2K vs Benchtop	• I like to use the M2K when possible, but it is not able to perform every task needed. I think with more practice I will get better with the benchtop equipment, but right now the M2K is my preferred method. • Bench top equipment is far more superior to the M2K board. The one thing I do like about the M2K board is for the possibility of doing the labs at home. I believe everything should be primarily done on the bench top devices while keeping the M2K as a last resort in case you cannot make it to class or a lab. • Benchtop equipment is, obviously, much more powerful and capable but takes longer to learn all functionality. M2K is easy and helped with the learning curve. Perhaps some training videos on M2K posted on Canvas would help students- something accessible and easy like YouTube, not some [embedded] Canvas video. • It is difficult sometime when having to use both I feel like the challenge is necessary for the student. I believe that the challenge of learning to use both is very beneficial to the entire process of the lab portion of the class. • There are pros and cons to both, but the M2K provides a simple interface to interpret data and makes changing variables quicker than on the benchtop.	5

Student Perception of Individual Labs

Figure 4 shows student perception of learning and engagement for lab exercises completed individually and with a lab partner using a Likert scale. Nearly 60% of students strongly agreed that individual labs helped them learn better and stay engaged through the exercise. In contrast, approximately 30% strongly agreed that group labs helped with learning and engagement. However, students in general perceived benefits from both individual and group labs with over 70% of students either strongly agreeing or somewhat agreeing that both scenarios can be helpful.

Supporting the data from Figure 4, Figure 5 shows that 50% of students perceive value in both teaming options: individual and group labs. 27% prefer individual labs, 9% prefer group labs, and 14% do not have a preference. Table 4 summarizes student comments on teaming. These comments reflect the sentiment in previous figures. Individual labs require each student to master the material, and it is clear when a student has not achieved the learning outcomes; however, peer-to-peer mentoring in a group is beneficial when facing a challenging lab exercise.

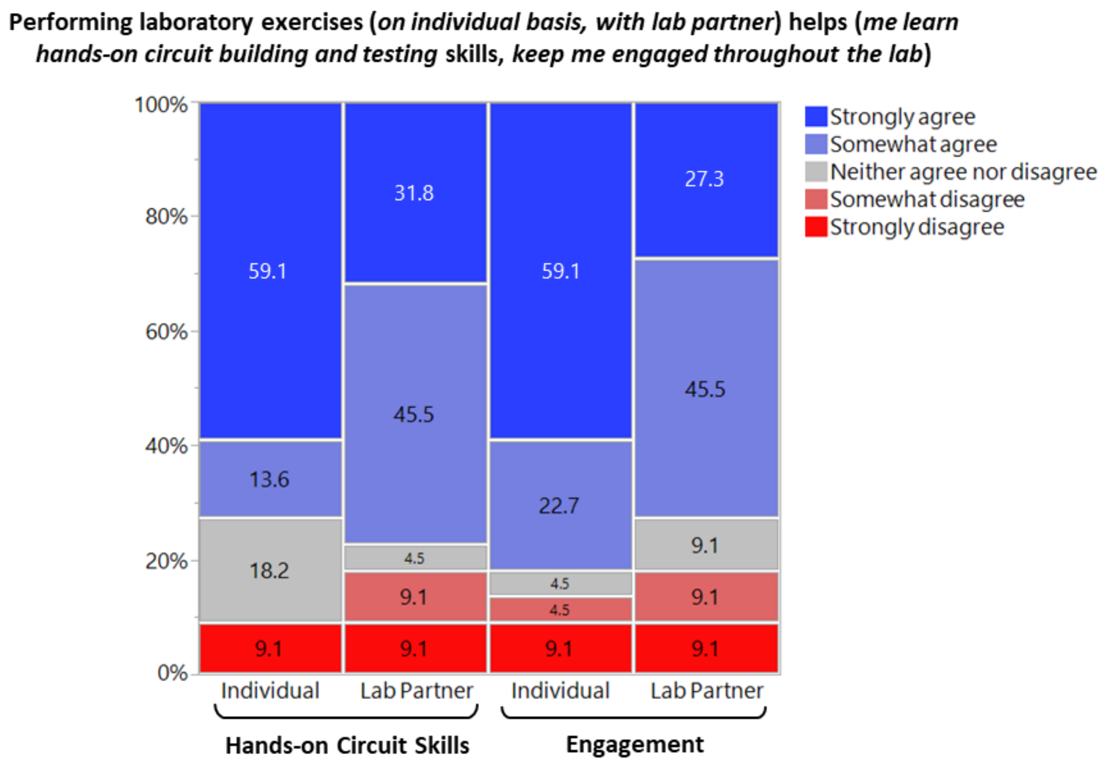

Figure 4. Student perception of learning and engagement for lab exercises completed individually and with a lab partner.

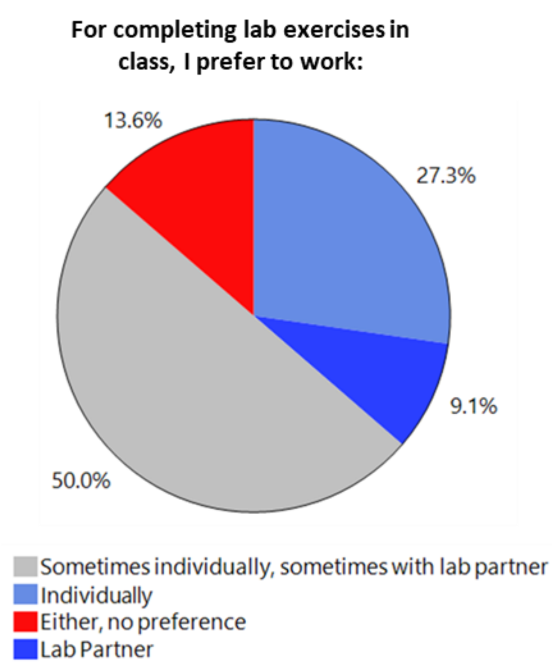

Figure 5. Student teaming preference for lab exercises: individually, lab partner, sometimes individually-sometimes with lab partner, either-no preference.

Table 4. Summary of selected student comments on student preference between individual and group labs. Number of students providing similar comments is also noted.

Category	Selected Student Comments	# of Students
Individual Labs	• I prefer to work individually in labs because I love to build the circuits. Another bonus to working by myself is that I get more practice with measuring the different aspects of the circuit. Which is very much needed for me. • I feel if you work with a partner sometimes they may know a lot about the objective and the other partner may have trouble understanding the objective if the partner knows everything. Individually you can know what you struggle with and get the help you need.	2
Lab Partners	• If you're by yourself, you have no idea if you're correct or not and can get bored easily. Having a partner allows for ideas to be bounced around to get to the correct answer. Partners also help you stay focused and not side tracked. Also, most people I know don't want to make the partner do all the work especially this far along in college so having a partner helps push people to pull their own weight. • Sometimes you can learn a lot from your lab partner, sometimes they're dead weight. • It just depends. If I am having a harder time with the given circuit I like working with a partner. I feel like the combination of the way both of us build and test the circuit is good for seeing different viewpoints.	3

5. Discussion

The previous results highlight some important advantages of the M2K device when used as a complementary tool for in-person classes. First, students are able to complete hands-on activities outside of class. 100% of students reported using the M2K to complete lab exercises they were unable to finish in class. 55% used the device to complete labs missed due to an absence. Makeup labs are time consuming, and with a heightened awareness about the spread of illness post COVID-19, student absences are common. Perhaps most interesting is that students are using the device for self-directed projects (36%) and coursework for other classes (27%).

Second, the M2K offers some features that are superior to basic benchtop equipment and 73% of students took advantage of these features. One feature is the direct export of data from all instruments to a data file on the student's computer. While technically possible for modern benchtop equipment, this might not be convenient especially if the equipment is not made by the same manufacturer. Another feature utilized is the availability of digital outputs. To demonstrate the principle of superposition, a primitive digital-to-analog converter may be constructed rather than just a resistive circuit with no actual function.

Third, laboratory space and equipment are finite resources, often requiring students to work in groups of two (and in isolated cases, groups of three). The M2K device alleviates this constraint by providing each student with a personal workbench. While students noted that working with a partner can be helpful, 60% of students strongly agreed that individual labs helped them learn better and stay engaged through the exercise. The M2K affords them this opportunity.

The student survey also highlighted some disadvantages of the M2K. Perhaps most importantly, it is primarily a learning tool, whereas benchtop equipment is used in industry. Because it lacks the robustness (and cost) of industry-grade equipment, the M2K software is prone to crashing especially with specific student laptops. There are also cases in which the student's laptop is simply not functioning or barely functional, or their device has a small screen, and these issues impede their ability to efficiently use the M2K. So, reliance on student-provided hardware is a limitation. Also, due to its compact size (which is also an advantage), the cable connections can become difficult to manage if using many pins simultaneously. And lastly, because of its portability, students may forget to bring the device to lab, or the device may be lost or unreturned at the end of the semester. Students do misplace the accessories (USB power cable, wiring cables), so these need to be replaced on 5-10% of returned devices. Since starting to use the device in Fall 2020, all units remain functional to the best of the authors' knowledge, with attrition being from non-returned units by students that have stopped attending class or drop the course.

6. Conclusions

Overall, the M2K provides student access to electronics test equipment outside of the classroom which supports self-directed learning. While this device could replace benchtop equipment if needed for online courses, 73% of students view it as a complementary resource. They value the ability to complete lab exercises outside of class. Students also view individual and group lab work as complementary with 50% preferring a combination of both approaches. The next most preferred mode was individual lab work (27%). Ideally laboratories would have a lab bench for each student, but this is probably not the case. The M2K provides the opportunity for individualized lab experiences. Resource permitting (M2K hardware, learning material development), the survey results summarized above suggest that supplementing traditional circuits education with M2K devices will improve learning outcomes by providing access outside of the classroom and the opportunity for individual lab experiences. While compact and powerful, the M2K cannot match the measurement performance and robustness of benchtop equipment. The authors see value in a compact, intermediate grade device with improved measurement specifications and robustness to combine the best aspects of the M2K and benchtop equipment.

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