AC 2011-2781: USING PORTABLE ELECTRONICS EXPERIMENT KITS FOR ELECTRONICS COURSES IN A GENERAL ENGINEERING PROGRAM

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Using Portable Electronics Experiment Kits for Electronics Courses in a General Engineering Program

Virtual instruments on a laptop and an accompanying collection of portable hardware serve as good supplements, if not replacements, for benchtop electronic equipment such as oscilloscopes, multimeters, and function generators. These tools can provide a new form of laboratory experience that frees students from traditional geographically-constrained settings and expands laboratory activities into more ubiquitous learning environments, allowing students to achieve laboratory objectives and complete the associated tasks at their individual paces. We hypothesize that this approach to hands-on electronics education will improve multiple learning outcomes within the ABET assessment framework, including outcomes (a) apply math and science, (b) conduct experiments and interpret data, and (e) solve problems. This paper presents our experiences using a custom portable electronics experiment kit (PEEK) in a general engineering program. The PEEK and the accompanying laboratory experiences were developed with NSF-CCLI support. Two electronics courses, ENGR 3014—Circuit Analysis and ENGR 3050—Instrumentation and Controls were selected for this research. As a supplement to regular face-to-face laboratory meetings, each student was given a PEEK to complete the pre-laboratory work and to complete any tasks that could not be finished during the laboratory period. The paper describes the features of the PEEK tool, the details of its implementation within the learning environment, and its effectiveness based on the assessment of the learning outcomes. This paper also discusses practical issues noted in the process of incorporating this learning model into day-to-day instruction, including (1) challenges encountered when the tools were used in a general engineering curriculum, where only a few electronics courses are offered, (2) methods to support students when they work on laboratory assignments off campus and after hours, and (3) different strategies to motivate students in lower- and higher-level classes when they use such tools in unsupervised environments.
Introduction

Pervasive computing power and the high-speed Internet have altered engineering education as they have altered other aspects of life. Virtual reality simulations and remote laboratories over the Internet provide “hands-off” experiments that are able to strengthen theory and enhance student comprehension [1]. These hand-off laboratories, however, do not facilitate hands-on skills such as circuit construction and the use of measurement equipment, which are important parts of problem solving and skills that are desired for students’ careers. Several recent engineering education projects, including “Lab-in-a-box” [2] and “the Mobile-Studio-Project” [3, 4], recognized these challenges and attempted to use portable devices to expand laboratory activity from traditional laboratory settings into more ubiquitous learning environments. Commercial educational tool manufacturers also identified this learning change and started to make tools that support this transformation [5]. In these efforts, virtual instruments and their respective collection of portable hardware serve as good supplements, if not replacements, for their traditional costly counterparts. Many of these new tools are made available on students’ laptops and provide additional forms of laboratory experiences that free students from traditional geographically constrained settings and expand laboratory activities into more ubiquitous learning environments. It is generally believed that this new learning model can offer advantages: (a) laboratory learning is no longer limited by logistic issues such as laboratory scheduling and resources (personnel, space, etc.), (b) students can achieve laboratory objectives and complete the associated tasks at their individual paces, and (c) the tools allow motivated students to explore much more than what is defined in laboratory instructions and push their learning to a higher level.

In our project, a portable electronic experiment kit (PEEK) was developed to support laboratory learning experiences occurring outside of the laboratory space [6, 7]. Here, we take advantage of National Instruments’ ELVIS (Educational Laboratory Virtual Instrumentation Suite) [8] drivers and their newly released myDAQ data-acquisition units [9] to assemble a powerful tool set to conduct electronics laboratories outside of traditional laboratory spaces. The tools were used in two undergraduate engineering curricula: one General Engineering program at East Carolina University and an Electrical and Computer Engineering program at Kansas State University [7, 10].

The development and improvement of the tools utilized in the project are introduced in a separate paper [11], whereas this paper focuses on our experiences in offering these tools in a Circuits class in the ECU General Engineering Program. The paper describes the means by which laboratory activities were expanded out of centralized laboratory space, instruments utilized to assess the effectiveness of the new interface, assessment results obtained from the project using pre- and post-surveys and the comparison of learning outcomes between experimental and control groups, and lessons learned from the experience given that the tools were introduced into the classroom for the first time.
PEEK Overview

The portable electronic experiment kit (PEEK) developed for this effort is illustrated in Figure 1. The kit set includes three primary components: a RASCL (Rapid Analysis and Signal Conditioning Laboratory) board [6], a myDAQ data acquisition unit [9], and a laptop. With National Instruments’ ELVIS (Educational Laboratory Virtual Instrumentation Suite) software [8] installed on the laptop, this kit can work as an equivalent to bench-top electronic test/measurement equipment that is normally available only in dedicated laboratory space, including digital multimeters, oscilloscopes, function generators, and many others. The RASCL board provides a large breadboard area and interfaces user circuits with the myDAQ unit. A 15" x 11.75" x 2.5" satchel-style case holds all of the PEEK components (see Figure 1.b) and allows students to easily carry the equipment off-campus.

Figure 1. The portable electronics experiment kit (PEEK): (a) kit setup and (b) PEEK with a case.

Project Implementation

To investigate how the proposed portable experiment tool can help student learning, the PEEK was used in a Circuits class during Fall 2010. The entire class, ENGR 3014-Circuit Analysis, contained three sections with a total of 44 students. Section 3 (12 students) was selected as the experimental group that would use the new tool. At the beginning of the semester, participating students first went through the required IRB process before each was provided with a PEEK. Laboratory activities associated with the course included 12 individual sessions, 11 of which were hands-on and involved circuit construction and equipment use (as listed in Table I below); the remaining session used MATLAB–based problem solving. Since this is the first electronics course in the ECU General Engineering curriculum, the first laboratory session was intended to train students on how to use
standard electronic test and measurement equipment; students learned to use a digital multimeter (to measure resistance, voltage, and current) and an oscilloscope (to observe waveforms generated by a function generator and to read parameters such as frequency, offset, and phase angle, etc.). Tasks in the second session were almost identical to those in the first session, except the students utilized their own PEEKs, which included virtual instruments (a computer-based DMM, oscilloscope, and function generator). After the training for both the bench-top and virtual equipment was complete, students were asked to use bench-top equipment for all in-laboratory tasks and to use PEEKs for tasks to be done outside of the laboratory space. To take better advantage of the new tool, most of the laboratory activities (Lab3-Lab6 and Lab8-Lab11) were restructured so that part of the procedural circuit-building work could be accomplished by students in advance. We anticipated that building circuits outside of the classroom would save laboratory time that could be utilized for higher-level discussion. Table II uses the RC circuit charging and discharging laboratory as an example to illustrate how tasks were moved around so that room could be made to have higher-level discussions during the laboratory session.

**Table I. List of Hands-on Laboratory Activities**

| Lab 1: Use of Electronic Test and Measurement Equipment |
| Lab 2: Use of Portable Virtual-Instrument-Based Electronic Equipment |
| Lab 3: Equivalent Circuits |
| Lab 4: Inverting and Non-Inverting Op-Amps |
| Lab 5: Summing Op-Amps |
| Lab 6: Charging and Discharging of RC Circuits |
| Lab 8: Course Project: Design of a Temperature Alarm (I) |
| Lab 9: Course Project: Design of a Temperature Alarm (II) |
| Lab 10: Course Project: Design of a Temperature Alarm (III) |
| Lab 11: Course Project: Design of a Temperature Alarm (IV) |

**Table II. Lab 6 - Charging and Discharging Capacitors**

<table>
<thead>
<tr>
<th>Before</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Lab Meeting Time</td>
<td>Pre-Lab Meeting Time</td>
</tr>
<tr>
<td>– Calculate 37% and 63% of 5V</td>
<td>– Calculate 37% and 63% of 5V</td>
</tr>
<tr>
<td>– Locate charging and discharging time constants</td>
<td>– Calculate time constant</td>
</tr>
<tr>
<td>– Build charging/discharging circuit</td>
<td>– Calculate time constant from charging/discharging voltage curves</td>
</tr>
<tr>
<td>– Find time constant from charging/discharging voltage curves</td>
<td>– Locate charging and discharging time constants</td>
</tr>
<tr>
<td>– Find time constant from charging/discharging current curves</td>
<td>– Build the charging/discharging circuit</td>
</tr>
<tr>
<td>– Find time constant from charging/discharging voltage curves</td>
<td></td>
</tr>
<tr>
<td>– Find time constant from charging/discharging current curves</td>
<td></td>
</tr>
</tbody>
</table>

As seen in the laboratory activity list, a four-week Temperature Alarm project was planned, where students were required to linearize an amplification circuit for a thermistor-based temperature sensor, a comparison circuit that compares the signal with reference voltages
corresponding to prescribed upper and lower temperature limits, and an alarming circuit that issues an alert when the temperature is beyond the range. This project required many calculations/derivations to select the appropriate resistance values before students could start building circuits. Circuit-building assignments consequently could not be accomplished as pre-lab assignments. Therefore, the project took advantage of the PEEKs differently: rather than use a PEEK as part of the pre-laboratory exercise, each student had the option to use a PEEK to complete their circuits afterwards if they could not complete all of their work during the meeting session. Given access to this tool, each student could theoretically keep up even if they were behind at some point during the project.

![Image](image.jpg)

**Figure 2. Student using a hair dryer to test his temperature alarm design.**

To help students when they worked independently outside of the laboratory after hours, a teaching assistant (a senior engineering student who had taken the circuits course in the previous year and had prior experience with the data acquisition software) was made available over the Internet four hours per week during evening times that all students agreed upon. Facebook and Skype were used as the primary connection tools that allowed students to approach their TA should they have questions.

**Assessment**

We anticipated that expanded laboratory learning enabled by the introduction of the PEEKs would bring many benefits. Self-paced work should allow better comprehension of the theory behind the circuits that students build in experiments relative to comprehension that occurs in the traditional laboratory model, where students often rush through building their circuits and spend little-to-no time on deeper thinking. Higher-level discussions should spark more insights and encourage understanding of material from more diverse perspectives. Referring to the ABET assessment framework [12], we hypothesized that this new learning experience would improve several learning outcomes. This paper assesses and discusses only ABET outcomes (a) apply math and science, (b) conduct experiments and interpret data, and (e) solve problems.
These learning outcomes were assessed with various instruments: (1) FE-style (FE: Fundamentals of Engineering Exam) questions were included on the final exam to assess outcomes (a) and (e). Ten multiple choice questions were asked; five for each outcome. The percent of students who responded correctly was recorded, and results for the control and experimental groups were compared using bar charts as in Figures 3 and 4. (2) Outcome (b) was assessed by evaluating the students’ abilities in three specific areas: (i) circuit construction; (ii) use of electronic measurement equipment; and (iii) interpretation of experimental data. Among these, the first two were based on instructor observations during the laboratory sessions, while the third was assessed with individual project reports. Rubrics were defined early in the semester to help with the assessment of each of these areas, as summarized in Table III. Results for outcome (b) are shown in Figure 5.

![Outcome a Assessment Results](image1)

**Figure 3.** Outcome (a) assessment results using five FE-style embedded questions.

![Outcome e Assessment Results](image2)

**Figure 4.** Outcome (e) assessment results using five FE-style embedded questions.
Figure 5. Outcome (b) assessment results using laboratory observations and project reports.

Table III. Rubrics for the “Ability to Conduct Experiments and Interpret Data” Elements.

<table>
<thead>
<tr>
<th></th>
<th>1 (Poor)</th>
<th>2 (Fair)</th>
<th>3 (Good)</th>
<th>4 (Very good)</th>
<th>5 (Excellent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Build circuits independently</td>
<td>Cannot build circuit even with help</td>
<td>Circuits built depending on help</td>
<td>Build circuits with major help</td>
<td>Build circuits with some help</td>
<td>Successfully build circuits without help</td>
</tr>
<tr>
<td>ii. Use test/ measurement equipment correctly</td>
<td>Cannot use equipment at all</td>
<td>Use equipment with many major mistakes</td>
<td>Use equipment with some major mistakes</td>
<td>Use equipment with some minor mistakes</td>
<td>Use equipment without problems</td>
</tr>
<tr>
<td>iii. Interpret data correctly</td>
<td>Cannot interpret data at all</td>
<td>Often interpret data wrong</td>
<td>Sometimes interpret data wrong</td>
<td>Occasionally interpret data wrong</td>
<td>Interpret data read without problems</td>
</tr>
</tbody>
</table>

Additionally, we expected that the opportunity to use the tools proposed here would increase students’ interest and enthusiasm for laboratory work, class, and even the engineering profession as a whole. To assess this assumption, an Opinions on Engineering survey adapted from the “Pittsburgh Engineering Freshman Survey” [13] (see the Appendix for details) was administered at both the beginning and the end of the semester to detect any possible changes in students’ attitudes towards the engineering profession.

The 38 questions were carefully examined and regrouped to note changes in students’ opinions with respect to eight different subjects. The question numbers for the eight subjects are presented in Table IV. For questions whose responses were reverse-ordered, the responses were first reversed so that a higher score would imply a favorable answer. The mean of each group was then found, and the results are summarized in Figure 6.
## Table IV. Question Groups to Collect Students’ Opinion on the Eight Aspects

<table>
<thead>
<tr>
<th></th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Problem solving</td>
</tr>
<tr>
<td>2</td>
<td>Interest in electronics</td>
</tr>
<tr>
<td>3</td>
<td>Teamwork</td>
</tr>
<tr>
<td>4</td>
<td>Job potential</td>
</tr>
<tr>
<td>5</td>
<td>Impact on society</td>
</tr>
<tr>
<td>6</td>
<td>Enthusiasm</td>
</tr>
<tr>
<td>7</td>
<td>Self-rewarding</td>
</tr>
<tr>
<td>8</td>
<td>Attitudes on engineering</td>
</tr>
</tbody>
</table>

Figure 6. Students’ opinions on eight subjects from the pre- and post-surveys.

### Discussion

During the semester, the students in the experimental group were asked to use the portable tools for all of the planned laboratory activities. Generally, the students demonstrated interest in such tools. The project, however, encountered challenges during the semester:

- **Overwhelmed Students**: ENGR 3014 is the first (and only) circuits course that the students take where they learn fundamental subjects like basic circuit concepts, theorems, analyses, and methods. Meanwhile, they also need to learn how to use standard bench-top electronics measurement equipment (i.e., digital multimeters, etc.). The introduction of the new tool, while it provided students with extra learning opportunities, added difficulty when students had to frequently switch...
between the bench-top and virtual versions of the same equipment, especially since this was the first time they were exposed to both.

- **Tool Readiness:** Everything in the PEEK set was new. The myDAQ data acquisition unit was introduced last summer, its components in the accompanying software required patches, and the RASCL board arrived with a new PCB design and a new layout, where certain functions had not been thoroughly tested. After the tools were presented to the students, any unexpected hardware/software slip-ups quickly turned student excitement into frustration.

- **Insufficient Preparation Time:** The laboratory documents were not able to be seamlessly integrated into the existing course plan due to limited preparation time. The integration of the hardware and software was not ready until the beginning of the semester, leaving the instructors insufficient time to thoroughly learn the equipment and prepare instructional materials (e.g., training materials).

- **Tool Complexity:** The RASCL board offers two sets of power and ground: one from the myDAQ unit supplied through the laptop via a USB cable, and the other from an accompanying AC adaptor. As indicated in [11], two sets of very similar labels on the breadboard strip confused some students and made their independent laboratory harder. The connections required to use the virtual function generator and oscilloscope were not clear. These issues added an extra level of complexity to the tool use and did not help students who had extremely limited experience in circuit prototyping.

- **Poor Support Outside of the Classroom:** The authors anticipated that it would be hard to provide students with help when they work off campus. It was worse. With the hope of building a virtual learning community, the instructor agreed to use Facebook and Skype (as the students requested) as the primary and secondary means of communication for afterhours support. The teaching assistant stayed online one hour Monday-to-Thursday evenings to offer help. However, social-network-based learning support did not work as desired. Students had many “more exciting” things that they wanted to share with their friends on Facebook than discussing which pin of the op-amp a piece of jumper should be connected to or why the LED indicator for the power did not turn on.

The authors believe that improving the tools and better incorporating proposed learning experiences with existing teaching approaches will definitely help. We have identified a few specific opportunities that should improve the experience:

1. Provide a demonstration video for PEEK training in addition to the paper-based tutorial. Visual training should be more efficient than paper-based material for the purpose of equipment operations.

2. Make a teaching assistant available at an easily accessible location a few hours per week after the laboratory/lecture meetings. Last time, the TA met and helped students more on campus during afterhours than they used online “office hours”.

3. For students in the first electronics course, requiring only the use of portable virtual equipment (rather than using both the portable and bench-top versions) might be preferable in order to reduce confusion. Once students grasp a set of tools, it should be straightforward for them to adapt to the other set and to switch between the two.
While the project encountered many difficulties in this first trial and not everything went completely as planned, a few important findings are worth mentioning. From the perspective of implementing projects that introduce new education tools:

- **In order to achieve educational goals, tools must be very carefully designed and thoroughly tested before they are presented to students.** Today’s students are impatient: when they experience technical obstacles during laboratory activities, they tend to avoid the problem by either working around it or completely giving up, instead of trying to troubleshoot and figure out the problem. Tool operation must be made simple in order for students to continue using the tool.

- **To observe the effectiveness of a new tool or a new approach in teaching/learning, frequent use of the interface is necessary.** In our case, we believe that expanded laboratory experiences can contribute to the improvement of multiple ABET student learning outcomes. However, some of these outcomes might not be observable due to insufficient practice with the new tools.

From the perspective of assessing laboratory work:

- **Although improved laboratory work should enhance some learning outcomes, it is hard to measure its contributions because of other factors.** As pointed out in [1], assessment of laboratory experiences in engineering education remains an area that warrants more research. In our project, the authors planned to use FE-style multiple-choice questions to assess ABET outcomes (a) apply math and engineering knowledge and (e) problem solving. Although many may agree that laboratories should help to improve student abilities in these two outcome areas and that comparing the experimental and control groups appears to be a sensible approach to evaluate the proposed tools, these two outcomes are a result of many other different factors (e.g., instructor, student background, assignments, etc.). In this project, assessment results from Figures 3 and 4 reflect the fact that the two instructors emphasized different topic areas based on their respective past teaching experience rather than reflecting the direct effects of the proposed laboratory innovations.

- **The outcome most directly impacted by the proposed tools should be ABET outcome (b) conduct experiments and interpret data.** One has to be careful, when viewing the results in Figure 5, to assume that the experimental group outperformed the control group in the three hands-on, skill-related areas because the data suffer issues such as the presence of two different evaluators and the small number of subjects in the experimental group (12). It is reasonable to assume that, with the added laboratory opportunities enabled by the new tools, students should see the most improvements in these areas. The assessment instruments used here (laboratory observations and project report evaluations) with prescribed rubrics, should help to generate meaningful results.

- **The Opinions on the Engineering survey appear to be sensible for the desired assessment purposes.** Pre- and post-modified Pittsburgh survey results illustrated in Figure 6 show that the proposed tools improved the students’ attitudes in many respects (interest in electronics, the belief that engineering positively impacts society, a sense of self-reward, and a positive attitude towards the engineering
discipline/career), while other aspects (problem solving, teamwork, job potential, and enthusiasm) remained unchanged. These data generally agree with the instructor’s intuitive assessment, except that the instructor thought the students should be more enthusiastic at the end of the semester. After they successfully made their temperature alarms work using the portable experiment tools, the students did feel a sense of self-satisfaction and demonstrate greater interest in electronics, and they displayed a more positive sense about engineering as a career and its impact on society. Because each student worked individually, it is understandable that the semester did not change the students’ opinions on teamwork. The current employment situation in this difficult job market can explain why there was no change in students’ opinions regarding their job potential. Problem solving ability, again, is affected by so many factors that it is hard to measure the influence that the proposed tools contributed in that area.

Conclusion

This paper presented the authors’ experiences in using a newly developed Portable Electronic Experiment Kit (PEEK) in a circuits course. Although the project did not fully follow the original plan, the project team learned lessons from this first trial which should help the project in the future. The paper summarized findings from the project implementation, laboratory assessment, and instrument development perspectives: educational tools must be carefully designed and tested in order to be effectively used by students; frequent access to tools is needed before noticeable changes can be observed; and laboratory work has the most impact on a student’s ability to conduct experiments, on their opinions/understanding of engineering, and on their attitude toward work.

Acknowledgements

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References


APPENDIX: Opinions on Engineering Survey

(This survey is modified from the Pittsburgh Freshman Engineering Survey®)

This is a survey to elicit your, as an Engineering student, opinions and feelings about engineering. Please do not spend more than 5 minutes to complete the questionnaire, so work as quickly as you can. For each statement about engineering, please fill in the number that corresponds to how strongly you disagree or agree with the statement.
1. I think that engineering is a rewarding career.  & 1 & 2 & 3 & 4 & 5  
2. I think that studying engineering is rewarding.  & 1 & 2 & 3 & 4 & 5  
3. The advantages of studying engineering outweigh the disadvantages.  & 1 & 2 & 3 & 4 & 5  
4. I don’t care for this career.  & 1 & 2 & 3 & 4 & 5  
5. The future benefits of studying engineering are worth the effort.  & 1 & 2 & 3 & 4 & 5  
6. The rewards of getting an engineering degree are not worth the effort.  & 1 & 2 & 3 & 4 & 5  
7. From what I know, engineering is boring.  & 1 & 2 & 3 & 4 & 5  
8. Engineers contribute more to making the world a better place than people in most other occupations.  & 1 & 2 & 3 & 4 & 5  
9. Engineers are innovative.  & 1 & 2 & 3 & 4 & 5  
10. I will have no problem finding a job when I have obtained an engineering degree.  & 1 & 2 & 3 & 4 & 5  
11. Engineering is an exact science.  & 1 & 2 & 3 & 4 & 5  
12. I enjoy taking liberal arts courses more than math and science courses.  & 1 & 2 & 3 & 4 & 5  
13. As a future engineer, I can do something to improve the welfare of society than most other professions.  & 1 & 2 & 3 & 4 & 5  
14. I am studying engineering because it will provide me with a lot of money; and I cannot do this in other professions.  & 1 & 2 & 3 & 4 & 5  
15. I am studying engineering because I am interested in making things happen; and I cannot do this in other professions.  & 1 & 2 & 3 & 4 & 5  
16. Engineers have contributed greatly to fixing problems in the world.  & 1 & 2 & 3 & 4 & 5  
17. An engineering degree will guarantee me a job when I graduate.  & 1 & 2 & 3 & 4 & 5  
18. Engineers are creative.  & 1 & 2 & 3 & 4 & 5  
19. Engineering involves finding precise answers to problems.  & 1 & 2 & 3 & 4 & 5  
20. I enjoy figuring out how things work.  & 1 & 2 & 3 & 4 & 5  
21. Technology plays an important role in solving society’s problems.  & 1 & 2 & 3 & 4 & 5  
22. Electronics is my thing; I love it.  & 1 & 2 & 3 & 4 & 5  
23. I feel I know what an engineer does.  & 1 & 2 & 3 & 4 & 5  
24. Studying in a group is better than studying by myself.  & 1 & 2 & 3 & 4 & 5  
25. I feel hands-on skills are my strength.  & 1 & 2 & 3 & 4 & 5  
26. I have strong problem solving skills.  & 1 & 2 & 3 & 4 & 5  
27. I am good at using electronic gadgets.  & 1 & 2 & 3 & 4 & 5  
28. Most of my friends that I ‘hang-out’ with are studying engineering.  & 1 & 2 & 3 & 4 & 5  
29. I feel confident in my ability to succeed in engineering.  & 1 & 2 & 3 & 4 & 5  
30. I prefer studying/working alone.  & 1 & 2 & 3 & 4 & 5  
31. I am good at designing things.  & 1 & 2 & 3 & 4 & 5  
32. In the past, I have not enjoyed working in assigned groups.  & 1 & 2 & 3 & 4 & 5  
33. I am confident about my current study habits or routine.  & 1 & 2 & 3 & 4 & 5  
34. I consider myself mechanically inclined.  & 1 & 2 & 3 & 4 & 5  
35. I consider myself technically inclined.  & 1 & 2 & 3 & 4 & 5  
36. I enjoy building things and make them work.  & 1 & 2 & 3 & 4 & 5  
37. I enjoy solving open-ended problems.  & 1 & 2 & 3 & 4 & 5  
38. I enjoy problems that can be solved in different ways.  & 1 & 2 & 3 & 4 & 5