# Teaching Introduction to Electronic Circuits in a Studio Format

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## Abstract

Introductory electronic circuits courses with a lab component are typically taught in a standard lecture-lab format where lecture and lab are taught as separate classes potentially by different instructors. The lecture portion of the course typically involves the Professor delivering a 'chalk-talk' about circuit analysis techniques and the lab portion of the course typically involves students measuring voltages and currents in provided circuits with electronic test equipment. Two major problems arise with this method of teaching: 1. Students often do not see the connection between what they are learning in lecture with what they are doing in lab and 2. Students often do not see a connection with what they are doing in lab with real-world applications. Without being able to directly implement what they learn in lecture to a practical and useful real-world example or problem, students become disinterested in the subject and may even choose to leave the major.

This paper discusses an attempt to modify the structure and content of an introductory electronic circuits course to make the course more engaging for students to hopefully increase retention of students within the major. The course's "studio format" (a course where lecture and lab are combined) focuses on providing students with multiple opportunities to directly apply what they are learning in lecture to real-world applications in a laboratory setting. The paper discusses the course's format and its weekly integrated lab activities. It then discusses the student and instructor reactions to the course and compares them with student and instructor reactions to the course taught in the traditional format. Finally, the paper discusses lessons learned and suggestions for future offerings as well as plans for tracking how the course affects student retention.

## Introduction

Introductory electronic circuits courses with a lab component are typically taught in a standard lecture-lab format where lecture and lab are taught as separate classes potentially by different instructors. The lecture portion of the course typically involves the Professor delivering a 'chalk-talk' about circuit analysis techniques and the lab portion of the course typically involves students measuring voltages and currents in provided circuits with electronic test equipment. Two major problems arise with this method of teaching: 1. Students often do not see the connection between what they are learning in lecture with what they are doing in lab and 2. Students often do not see a connection with what they are doing in lab with real-world applications. Without being able to directly implement what they learn in lecture to a practical and useful real-world example or problem, students become disinterested in the subject and may even choose to leave the major.

A few options exist to remedy the aforementioned problems that arise with separate lecture and lab courses:

1. Modify the content of the lecture and lab courses so that the material presented in each course more closely aligns.
2. Create a “flipped classroom” where students watch prerecorded lectures at home, leaving all class time for hands-on activities and labs that apply the lecture material.
3. Combine the lecture and lab courses into a single “studio” course so that an instructor can immediately introduce a lab that applies lecture material.

Although Option 1 is a viable option (and implemented successfully at many universities), it still does not allow for immediate application and integration of lecture material in the laboratory setting. Students may go to lecture on Monday and then lab on Friday, thus leaving many days in between introducing the material to applying the material. This problem could possibly be remedied if university resources (room availability, staffing, etc.) allowed for closer scheduling of lectures and labs. Still, if the lecture and lab courses are taught by separate instructors, one instructor may go at a different pace or chose to emphasize different topics than the other so that once again topics in lecture and lab do not quite align.

Option 2 is a viable option and has been proven successful [1-4], but does require considerable effort on the instructor’s part to develop video lecture content.

Option 3 is, in our opinion, the best option to remedy the problems associated with lecture and lab courses as a studio course provides students with multiple opportunities to immediately apply what they are learning in lecture to real-world applications in a laboratory setting without too much additional work for the instructor. Option 3 has proven successful in other subject areas at our institution [5-6] and in electric circuits at other institutions [7-9] and thus we deemed it the right approach for our study.

Therefore, this paper discusses an attempt to implement a ‘studio format’ introductory electronic circuits course to remedy the problems associated with separate lecture and lab courses and make electronic circuits more engaging for students. The paper discusses the course’s format and its weekly integrated lab activities that make use of modern hardware and software tools. It then discusses the student and instructor reactions to the course and compares them with student and instructor reactions to the course taught in the traditional format. Finally, the paper discusses lessons learned and suggestions for future offerings as well as plans for tracking how the course affects student retention.

## Course Format and Content

Our Electronic Circuits studio course was offered for the first time in Fall 2016. It met twice a week in 3 hour blocks, for a total of 6 hours of class time. The classroom where the studio class was held contained twelve electronics lab benches (equipped with a computer, two power supplies, two digital multimeters, one oscilloscope and one function generator) around the perimeter of the room and twenty-five student desks (in five rows of five desks) in the center of the room.  Twenty four students from either electrical or computer engineering majors took the course.

Table I shows the weekly course topics and associated lab activities for the ten-week course. Within the two three-hour sessions, the instructor could easily transition between lecture and lab components of the course as students could sit at the desks to be presented with new lecture content and then go to the lab benches at the perimeter of the room to immediately put the concept to practice.  Also note that we conducted a 5 week long PCB project during the second half of the course.

Table I. Weekly Course Topics and Associated Labs/Activities

| Week | Topic | Lab/Activity |
|---|---|---|
| 1 | Circuit Theorems Review | CATE, LTSpice |
| 2 | Capacitors / Inductors | Homegrown capacitor/inductor |
| 3 | AC Circuits | Intro to Bench Top Equipment |
| 4 | AC Circuits | Intro to Analog Discovery |
| 5 | Op-Amps | Breadboarding op-amp circuits |
| 6 | Midterm | Eagle PCB Tutorial |
| 7 | First Order Circuits | PCB Project continued, Breadboarding RC blink circuit |
| 8 | Second Order Circuits | Eagle PCB Layout |
| THANKSGIVING BREAK | | |
| 9 | Review | Soldering exercise |
| 10 | Final Exam | Final Project Assembly & Testing |

In the following subsections we describe each weekly labs/activity in more detail.

*Week 1 – CATE, LTSpice*

During the first week of class, we reviewed circuit theorems (voltage divider, current divider, KCL, KVL, Superposition, Thevinin/Norton) that students were expected to know from their pre-requisite classes.  We introduced two open source software tools that could help students with the review: CATE [10] – a new homegrown online tool that solves circuit problems step by step and then presents randomized circuit diagrams for students to solve, and LTSpice – a powerful circuit simulation tool.  After a brief lecture, students were able to spend the rest of the studio class time solving circuits on the computer using CATE and LTSpice.  Although students could also have easily just solved circuits with pencil and paper, having access to these software tools allowed them to 1. Have instant feedback and step-by-step guidance on different circuit analysis problems (CATE) and 2. Get used to using a tool that they would see again later in the course and in more advanced electronics courses (LTSpice).

*Week 2 – Homegrown Capacitor and Inductor*

During the second week of class, we introduced capacitors and inductors and their equations for voltage, current, power, and energy.  Instead of just solving problems on pencil and paper, we asked students to build their own capacitors and inductors out of regular household items and determine how varying parameters (such as type and amount of material) affected the capacitance or inductance of their device. Students built parallel plate capacitors out of aluminum foil and waxed paper, plastic wrap, or printer paper and varied the size of each device. They used a capacitance meter to measure the capacitance of each capacitor to see how changing the area and material affected the capacitance. They built inductors by coiling different amounts of solid core 22 gauge wire around a four-inch nail. They connected each inductor to a D-cell battery and counted the number of staples their inductor could pick up to observe the effects that the changing number of coils has on inductance and its resulting magnetic field. Through this activity, students were able to achieve a better understanding of what capacitors and inductors actually are and how their properties can be varied.

*Week 3 – Intro to Bench Top Equipment*
During the third week of class, we instructed students to build DC and AC circuits in the lab (with decade box resistors and capacitors) and take measurements with the bench top electronics test equipment. Students learned how to use the Digital multimeter, DC power supplies, function generator, and oscilloscope. Students also continued to use CATE and LTSpice to practice AC circuit problems.

*Week 4 – Intro to Digilent Analog Discovery 2 Module*
During Week 4, we continued the discussion of AC circuits and asked students to build the same circuits they built during Week 3, but to use the Digilent Analog Discovery Module instead of the bench top lab equipment. The Digilent Analog Discovery 2 module is a portable USB laboratory that gives you a power supply, function generator, oscilloscope, logic analyzer, and other functions all in one. It is small enough to fit in your pocket, but powerful enough to replace a stack of lab equipment, providing engineering students the freedom to work with analog and digital circuits in virtually any environment, in or out of the lab. [11] This activity allowed students to gain more practice with building and measuring circuits and empowered them to see they could do much of their circuit labs in the comfort of their own home.

*Week 5 – Breadboarding Op-amp Circuits*
During Week 5, we asked students to build an inverting amplifier circuit and a summing amplifier circuit on a bread board with through-hole resistors and an 8-pin DIP 741 op-amp IC. The students had to first design and simulate their circuits in LTSpice and then build their circuits on a breadboard and make use of either the bench top equipment or the Analog Discovery 2 module to power, source, and measure the output of their circuits. This lab proved to be the first experience many of the students ever had with breadboards and proved to be the first experience all students had with reading a datasheet, designing, simulating, building, and testing a circuit.

*Weeks 6 - Eagle PCB Tutorial*
During Week 6, we did not present any new material (as it was midterm week), but asked students to watch and follow along with an online Eagle PCB tutorial [12] to learn how to layout a printed circuit board (PCB). Other instructors had experimented with a PCB project for an introductory circuits lab in the past [13] and thus we decided to try to conduct a PCB project in the studio course, now with more modern PCB layout software.

*Week 7 – Breadboarding RC blink circuit*
During Week 7, we continued the PCB project by asking students to find a simple, real-world circuit online for which they wished to design a PCB. Once they decided on the design, they were asked to find the components on a distributer's website and create a BOM (Bill of Materials) for the design. In addition to continuing the PCB project, we asked students to follow an Instructable [14] to build a circuit on a breadboard that blinked an LED according to the time constant of the resistor/capacitor pair values in the circuit. This lab reinforced the first order circuit concepts they learned in lecture, while allowing them to gain more practice with building, measuring, and testing a practical circuit.

*Week 8 – Eagle PCB layout, LTSpice*
During Week 8, students completed the PCB layout of their chosen circuit and sent me the Gerber files and BOM for their designs so we could order their PCBs and their electronic components. They also continued to use LTSpice to simulate an RLC smoothing circuit to be put on the output of a Digital to Analog converter to practice the second order circuit concepts they learned in lecture.

*Week 9 – Soldering exercise*
During Week 9, students learned how to solder surface mount components (many had never done this before), so that they would be prepared to assemble their PCBs when they arrived the following week. They also continued to make use of CATE and LTSpice to practice all concepts learned in the course and prepare for the final exam.

*Week 10 – PCB Assembly and Test*
During the last week of the course, students took their final exam and assembled and tested their PCBs using the soldering skills they learned in Week 9 and the electronic test and measurement equipment they learned throughout the quarter. Having the Thanksgiving break between the time we ordered the PCBs and the time we assembled them gave us the time we needed to receive the boards on time before the end of class. Students were also required to write a paper in the double column IEEE conference paper format about the design, build, assembly, and test of their PCB project.

**Assessment**

In order to access the effectiveness of the studio course we anonymously surveyed the students in the studio course and anonymously surveyed the students in the traditional course taught by the same instructor during the same quarter. The survey consisted of 12 statements where students had to select on a Likert scale if they 5 – strongly agreed, 4 – agreed, 3 – were indifferent to, 2 – disagreed, or 1 – strongly disagreed with the statement. The survey also had two open ended questions where the students could write about what they liked and didn't like about the course. Of the 24 students in the studio course, 21 responded to the survey. Of the 46 students in the traditional lecture course, 43 responded to the survey (with 13 out of the 43 reporting having the same instructor for the separate laboratory course). Note that when registering for the course, the students did not know that one of the courses would be taught in a studio format, so there was no initial bias of students preferentially choosing one course format over the other.

Figure 1 reports the average level of enjoyment students had in the studio course (shown in blue) vs. the traditional separate lecture and lab course (shown in orange). The traditional course results are broken into three components where the students could rate their lecture and lab courses separately. It is clear from the graph that students enjoyed the studio course and students in the traditional course, enjoyed their lecture. However, students in the traditional course did not enjoy their separate lab course as much - even if they had the same instructor for both lecture and lab.

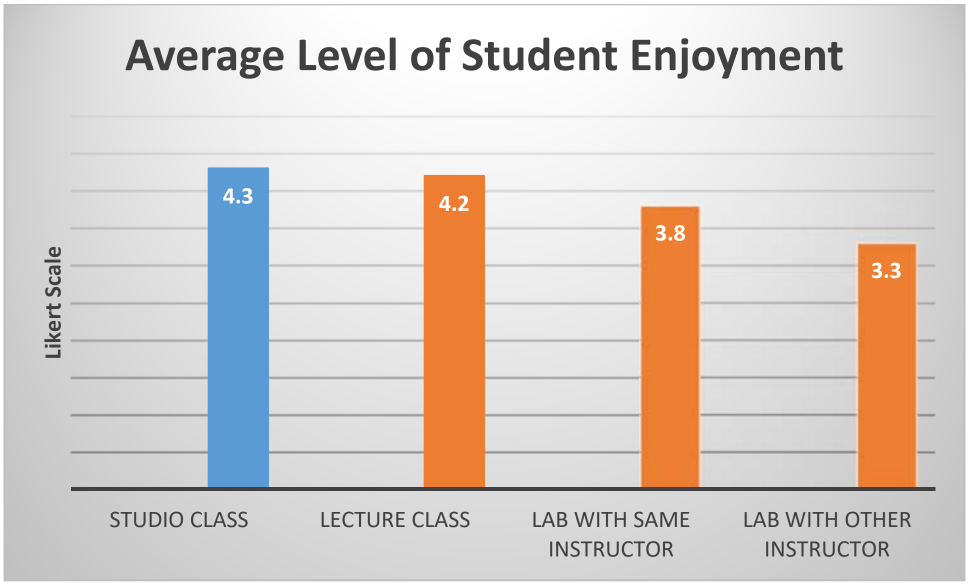


*Figure 1: Level of Student Enjoyment*

Figure 2 reports the average levels of lab usefulness for both the studio style course (blue) and traditional style course (orange). It is clear from the survey data (although not statistically significant due to the small sample size) that the studio style course better allowed for 1. Labs to be well aligned with lecture topics, 2. Theoretical concepts to be put to practical use, 3. Increased student confidence in ability to use the lab equipment, and 4. Increased student feel for real-world applications.

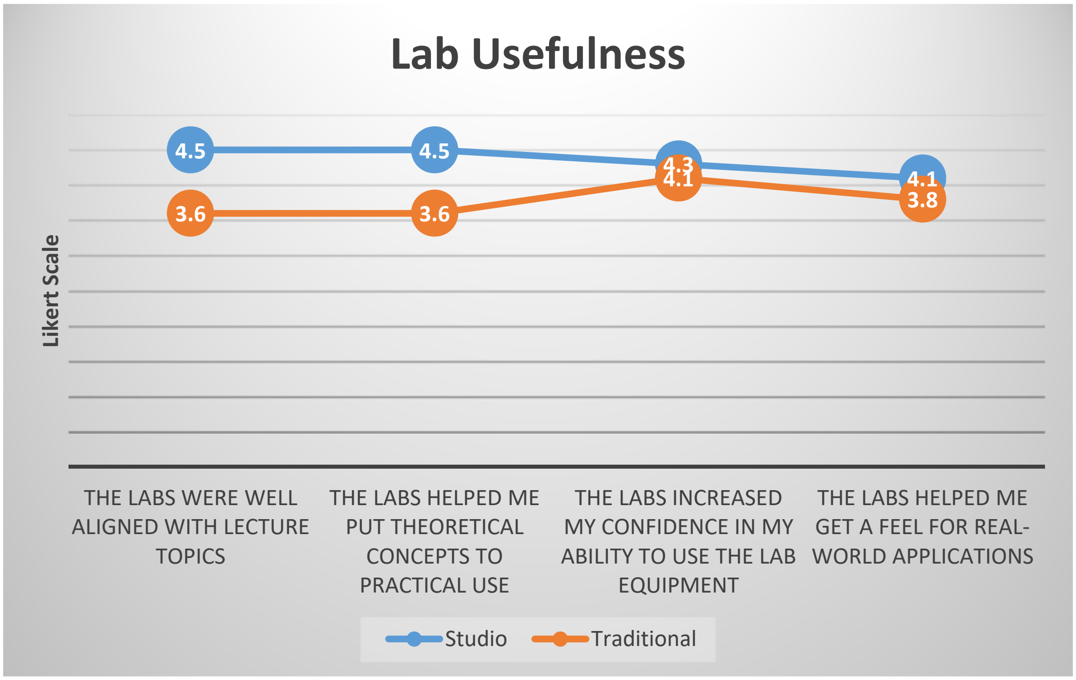


*Figure 2: Average Levels of Lab Usefulness*

Furthermore, the open-ended comments about the studio course further endorsed its usefulness. Two particularly telling comments are quoted below:

> *"I loved the studio style setup. It helped me learn the material a lot easier than my friends in other classes. The labs we had were reflective of the material and had a point to them, while my friends in other style setups had pointless labs and didn't understand the material as well as I did. 11/10 would take this style of class again."*
>
> *"The studio class was effective because immediately after we had lecture we would apply it in lab. Also, if lectures ever ended early, we would have more lab time and vice versa. I would want to take another studio EE class again."*

Figure 3 reports average comments about retention. Students were posed the same statement in two different ways to remove the potential bias from presenting survey questions in a positive manner. The first statement read, "After taking the <class>, I feel more confident in my decision to be an electrical or computer engineering major" while the second statement read "After taking the <class>, I no longer want to be an electrical or computer engineering major." Students in the traditional class were given the two statements for both their lecture and lab courses while students in the studio class were given the two statements for their single studio course. It is clear from the data (although again not statistically significant due to the small sample size) that the studio course (blue) helped students feel more confident in their decision to be an electrical or computer engineering major (and feel less of a desire to leave the major) than the traditional course (orange). Note that not a single student from the studio course marked a 5 for wishing to leave the major, whereas three students from the traditional course did. It is also evident that the lab portion of the traditional course was weaker than the lecture portion of the traditional course from the standpoint of student retention.

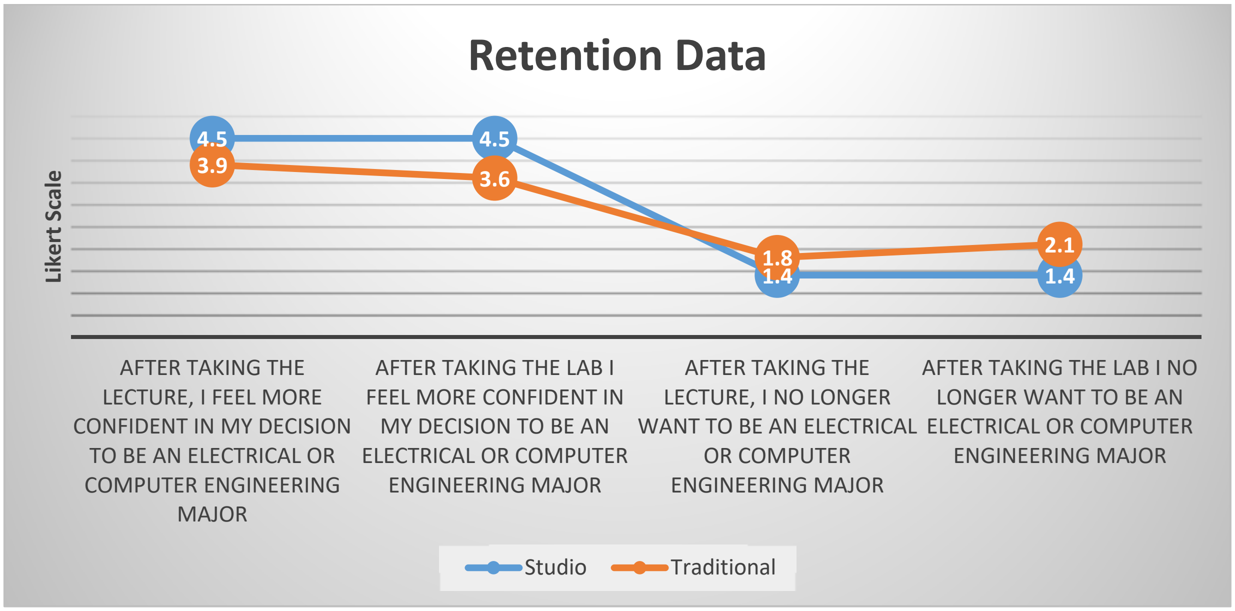


*Figure 3: Retention Data*

Finally, Figure 4 illustrates the average final exam grades with standard deviations for both the studio course (blue) and traditional course (orange). We administered the same final exam to both courses and the exams were graded with the same rubric by the same instructor. Prior to taking the course, the students in the traditional course had an average cumulative GPA of 3.09/4.0 and an average grade of 3.13/4.0 in the direct pre-requisite course whereas the students in the studio course had an average cumulative GPA of 3.10/4.0 and an average grade of 3.18/4.0 in the direct pre-requisite course, suggesting virtually no difference between the academic performance composition of the two classes.

The final exam data show that the studio course had a slightly higher average and a slightly lower standard deviation than the traditional course. Although the data suggest the studio course helps students achieve a better understanding of the course material over the traditional course, because the sample size was small, this result is not conclusive. Also, the lower standard deviation in the studio course grades could just be a result from the class size of the studio course being about half the size of the traditional course. It is also worth noting that the DFW rate (percentage of Ds, Fs, and Withdraw grades assigned) in the studio course was 8% whereas the DFW rate in the traditional course was 14% (but again, because the sample sizes were small and the traditional class was about twice the size of the studio class, these data are not conclusive).

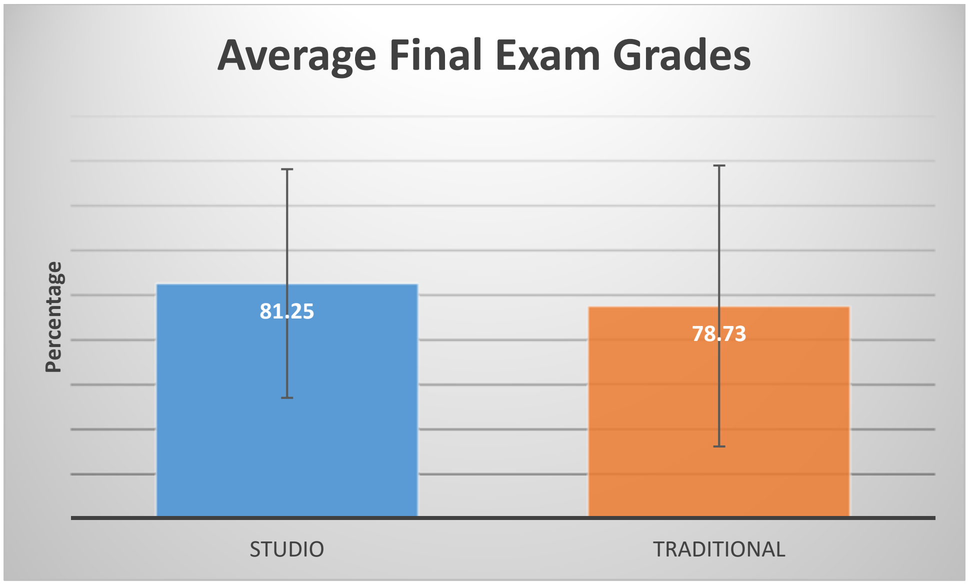


*Figure 4: Average Final Exam Grades*

**Discussion**

The assessment data suggest that the studio style course helped to alleviate the problems associated with a traditional separate lecture and lab course. The students in the studio style class were clearly able to see the connection between what they were doing in lecture with what they were doing in lab and were better able to see a connection with what they were doing in lab to real-world applications. The studio style course lead to increased confidence in a student's decision to stick with their major and perhaps an increased understanding of course material over the traditional course.

Most of the hiccups and lessons learned in the course stemmed from the 5-week long PCB project. Having each lab pair select a different (and somewhat random) circuit to implement on a PCB turned into a logistical challenge. First of all, some students selected circuits that they didn't completely understand (and thus didn't really know how to test). Second of all, some students selected components that were backordered or not available in the desired package size. Third of all, in order to get a discount in shipping, the instructor ordered parts for all projects under one order and then had to spend an entire day sorting and labeling parts when the order arrived. Lastly, as the PCBs just arrived on the last day of class, there was not enough time for thoroughly debugging and testing the assembled PCBs. During the next implementation of this course, we not only recommend starting the PCB project earlier in the course, we recommend picking a single circuit for the entire class to implement that makes use of circuit elements the students are familiar with.

We are hopeful from the enjoyment and retention data that offering the studio style course will indeed lead to increased retention of students in the electrical and computer engineering majors. We plan to track the 24 students from the studio style course and the 46 students from the traditional style course from this study over the next two years to see if there is indeed a difference in retention among the two cohorts. If there is an improvement, we will recommend that the department convert all of its intro circuits courses over to the studio style format.

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