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Paper: Necessity Brings Out a Welcomed Laboratory Change

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Necessity Brings Out a Welcomed Laboratory Change

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Abstract

The COVID-19 pandemic has disrupted much of the education community[1-6]. Engineering laboratory courses are particularly hindered by the students being denied access to the institutional equipment in the university laboratories. This puts into question how to best provide the hands-on laboratory experiences during the pandemic that the laboratory classes are intended to provide. We took this opportunity to make a change to how our department provides suitable laboratory equipment for student use in order to improve the students' remote laboratory experience. It required a modest investment that was fortunately provided by COVID-19 relief funds and has been met with positive student feedback. This paper is a case study of how our electrical engineering (EE) department's laboratory courses have been adapted in response to the pandemic.

Introduction

The conclusion of the referenced article by Ozadowicz[1] points out that in spite of all the disruptions there also have been improvements to educational processes brought on by the COVID-19 pandemic, including that it *caused a discussion on the need to modernize teaching methods with new technologies and tools*. As the summer of 2020 approached our EE department pondered how to implement its fall laboratory courses appropriately without the students meeting in the university's laboratories, as the university's response to the pandemic required. We considered conducting the laboratories using only virtual, simulated laboratory experiments; although, limiting the students to simulated laboratories does not afford the student the opportunity to work with real hardware and to face, identify, and overcome realistic implementation issues. The latter we believe are essential components of the intended student laboratory experience. So we had to come up with an alternate laboratory hardware plan and take action in preparation for the fall semester.

The paper is organized as follows: a discussion of remote laboratory electronic equipment is followed by a review of educational research questions, then a summary of the difficulties encountered and overcome, then educational enhancements afforded by the laboratory change, then a discussion of the application of the flipped classroom to the remote laboratories, and finally a discussion of learning assessment during the pandemic.

Remote laboratory equipment

We identified the National Instruments (NI) myDAQ instrument as a candidate mini electronics laboratory that each individual student could use to do the required laboratory work in their remote work area. The myDAQ is limited to audio frequencies, powered and controlled by the student's personal computer, and provides the basic functions of what the institutional equipment in the university's laboratories provide but which are now closed due to the pandemic. We believe that the myDAQs capabilities are adequate for remote Electronics, Control, and Circuits laboratory courses during the pandemic.

In the early summer of 2020 the EE department proposed to the College of Engineering the idea of purchasing myDAQs for loan to laboratory students and subsequently received incremental funding to procure a total of 340 myDAQ units to loan to the students. A first set of two hundred myDAQs were purchased in July of 2020, then a set of 90 more in September of 2020, and finally a set of 50 more in December of 2020. With an educational discount the university purchased the first two sets at a unit cost of $200 each, and by the time that the third set was ordered the educational price had increased to $208 each, giving us the impression that the popularity of the myDAQs was increasing during the pandemic. Since December of 2020 the price has further increased so we were fortunate with our limited budget to have been able to procure enough for our remote labs. The myDAQs were allocated to the EE laboratory courses that were deemed of highest priority, and arrangements were made to distribute the myDAQ units for loan to the students through the campus bookstore.

An alternate option for remote laboratory equipment also considered was to utilize the Arduino converted into a form of electronics lab. The Arduino is popular among engineering students, especially those interested in programming. It offers features that allow it to provide the capabilities of signal generation, measurement, and display; although, the additional effort required to customize the Arduino hardware and software for each different electronics laboratory exercise was considered to be essentially a laboratory exercise in itself, so it was not chosen. In comparison the myDAQ is a relatively more professional, modestly priced laboratory instrument that is dedicated to and ready out-of-the-box for the laboratory measurement exercises that our EE courses intend.

Difficulties encountered

There were some difficulties that were encountered related to making the change to base the remote pandemic laboratory courses on the use of the myDAQ, including distribution to the students, retraining to overcome the learning curve involved with the change, and revising the course curriculum to specifically accommodate the new laboratory equipment. There were difficulties encountered in preparation for making use of the new remote equipment. The logistics of distributing the new remote laboratory equipment to the students had to be worked out during the summer of 2020 in preparation for the change to be implemented in the fall 2020 semester. An arrangement was made with the university bookstore for the EE department to provide the bookstore with the new equipment, individually packaged with blank student loan agreement forms and for students to come to the bookstore individually to check out their allocated equipment. Students remote from the local area can have the bookstore ship the equipment to them. There was a learning curve for the professors to have to quickly overcome in order to master the use of the myDAQ. What helped minimize that learning curve is that the EE department had quickly recorded a series of videos in preparation showing professors how to set up the myDAQ unit and make general use of its features for our laboratory courses. There were also difficulties encountered modifying the courses to accommodate the myDAQ. The institutional equipment in the university laboratories affords the students with more options, power, and greater frequency bandwidth to work with than the myDAQ is able to provide (powered only by a laptop computer through a USB port). So the engineering laboratory curriculum, and the laboratory experimental procedures for the students to follow, had to be revised to make do with use of less power and confinement to the audio band of frequencies in order to accommodate the myDAQ instrument. The EE department determined that it would be most effective for the remote fall 2020 laboratory students to have pre-recorded videos available to help them learn to make proper use of the new equipment; whereas, the department also realized the considerable scope of producing such a considerable number of tutorial videos so quickly. The EE chair (a co-author of this paper) decided to propose the video recording project to the College of Engineering for approval prior to sponsoring several of the laboratory course instructors with stipends over the summer of 2020 to record a series of myDAQ instructional videos for each of their laboratory courses. That approval was granted, sponsored by the Coronavirus Aid, Relief, and Economic Security (CARES) Act: Higher Educational Emergency Relief Fund. It turned out that our EE department received approval to record more remote instructional videos than any other department at our university, suggesting that our department might have made more of a unique effort to prepare during the summer of 2020 for the coming pandemic-mode remote teaching scenario than other departments. Fortunately all these difficulties were overcome. The myDAQs were procured on time, the tutorial videos for the students were recorded and made available online, and the bookstore distribution of the myDAQs for the fall semester students was coordinated. The distribution of the myDAQ to the students began during the first week of classes only a few days late. A photo of a myDAQ unit is shown below in Fig 1. It’s about the size of a large cell phone.

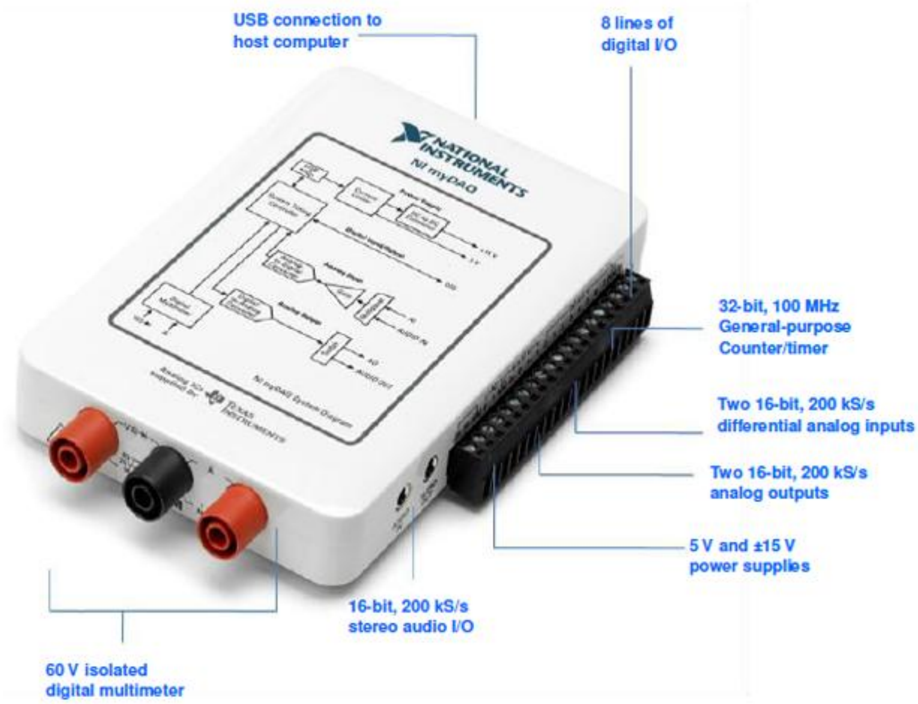


Figure 1. NI myDAQ instrument.

Educational enhancement

Active student engagement is essential to productive learning outcomes in laboratory courses. With each student provided access to a myDAQ instrument and pre-recorded laboratory tutorial videos, the student has the opportunity to engage with the instructor during an online class session and accomplish the laboratory exercises themselves, either synchronously guided by the instructor or asynchronously on their own. Thereby the student is equipped with a more flexible set of engagement options during this pandemic while still having a laboratory experience very similar to what students prior to the pandemic had using the institutional equipment installed in the university's laboratories.

One interesting *benefit* of this change is that the myDAQ doesn't provide enough current to burn out the TO-92 packaged BJT transistors used in our electronics laboratories. That had been an issue for some of the students prior to the pandemic doing their laboratory work using the more powerful institutional equipment in the university's labs and neglecting to set the power supply current limit properly. In that sense using the myDAQ makes the laboratory work a little less risky for the student. When a student prior to the pandemic would burn out a component during a laboratory class conducted in the university laboratory facilities then that student had the instructor and the other students in the same laboratory class immediately available to ask for a replacement part, but with each student operating remotely during this pandemic the student doesn't have that option. The remote students might be encouraged to remain engaged with the laboratory course activities – and thereby have a more productive remote learning outcome – when not discouraged by any risk of burning out any of the limited number of electronic kit components in their remote possession.

Another improvement that the myDAQ brings to the students laboratory experience is that it includes a Bode Analyzer utility that automates the measurement and plotting of frequency response sweeps. It saves the student significant time in measuring amplifier, filter, and control system circuits that otherwise would have to be done by manually taking measurements at tens of frequencies for each circuit and collecting hand-written data that might not be transcribed correctly. Thereby the myDAQ Bode Analyzer utility improves the quality of the student measurement data by avoiding hand transcription data errors.

Lessons learned for flipped classroom laboratory

A considerable number of our students had recently essentially requested a flipped classroom[7] format – without calling it that – for the remote electronics laboratory courses. We've since implemented that in some laboratory courses, and it now seems to be working well within the remote teaching scenario during the pandemic. During the summer of 2020 our department took the initiative to record several instructional series of videos specifically customized to instruct how to use the myDAQ instrument to properly conduct the respective laboratory exercises for our various EE courses. Those videos allow the laboratory students to be prepared for and comfortable with the given laboratory exercises using the myDAQ at their remote location and were made available to the fall 2020 laboratory students. Furthermore, in the Student Perception of Teaching (SPOT) student surveys done at the end of the fall 2020 semester students had emphasized the value of the pre-recorded laboratory instructional videos. They suggested that it would be an improvement for the instructor to focus class time on answering student questions after the students do their remote laboratory work on their own before class using the pre-recorded myDAQ instructional videos. (Detailed laboratory exercise instructions are all contained in the pre-recorded videos). These suggestions have now been put into practice during the spring 2021 semester, essentially flipping the (remote) laboratory classroom, with the spring students given access to both the department-sponsored basic myDAQ tutorial videos as well as the course-specific instruction-oriented recordings of the laboratory Zoom sessions from the fall semester. The current spring semester students are now expressing that those pre-recorded laboratory instructional videos are very helpful to them in completing their current laboratory exercises remotely. So it has been observed that active learning is enhanced during laboratory class sessions with the students having access to pre-recorded laboratory project instructional videos.

Another unique benefit of this flipped mode of remote laboratory classroom, especially in the context of pandemic remote teaching, is that any Internet outage or problem experienced by a student or the instructor during the scheduled remote class session does not detract from the instructional component of the class. The instructional component is supposed to be studied by the students by watching the pre-recorded online tutorial videos prior to the scheduled class time. To deal with Internet outages during scheduled class time we've found that it's beneficial for the instructor to simultaneously host a non-VOIP telephone conference line along with the Zoom class session so that any student who loses Internet connection during the class session can continue participating with the class on the audio conference line. Even the entire class could immediately switch from Zoom to the audio conference in case the instructor experiences a loss of Internet service during the class. There have been several instances for which a student did not completely lose Internet service but that it degraded enough to make that student's Zoom audio useless: In each case those students were able to immediately continue participating in the class session using the dial-in conference audio. During the first remote class session of the semester all the students are directed to temporarily step away from the Zoom session and dial into the audio conference as a sort of drill and training for the possibility of an Internet outage.

Our attitude towards adaptation of the laboratory courses in response to the pandemic seems similar to what Andrews, et al., report[2] also in response to the current pandemic. They deemed the laboratory exercises to be essential enough to the learning objectives that they did not want to defer entirely to virtual laboratories but rather wanted the students to have practical laboratory experiences despite not being able to conduct them on campus and even came up with clever student exercises involving household items. Our use of the pre-recorded videos to help students prepare for the remote laboratory exercises appears to be similar to the interactive dynamic online laboratory manual done for the Bristol project as mentioned by Gamage, et al.[3] Gamage mentions the probability during the current pandemic of graduating some of the students without adequate laboratory skills due to use of virtualized laboratory courses entirely dependent on simulations. We intend that the change we've made to our laboratory courses to equip the students with function lab equipment to use at their remote locations will maximize the probability that all students are able to gain suitable practical laboratory experience that is important for their career. Vutukuru[6] reports that remote electronic laboratory students were more engaged and eager to learn by building circuits in the comfort of their own homes than when on campus. Vutukuru also reports that laboratory exercises were creatively adapted so that students got a full laboratory experience though remotely. We believe that the adaptability and innovation that Vutukuru discusses is a key component that can lead to positive student laboratory experiences in spite of the pandemic.

Educational research

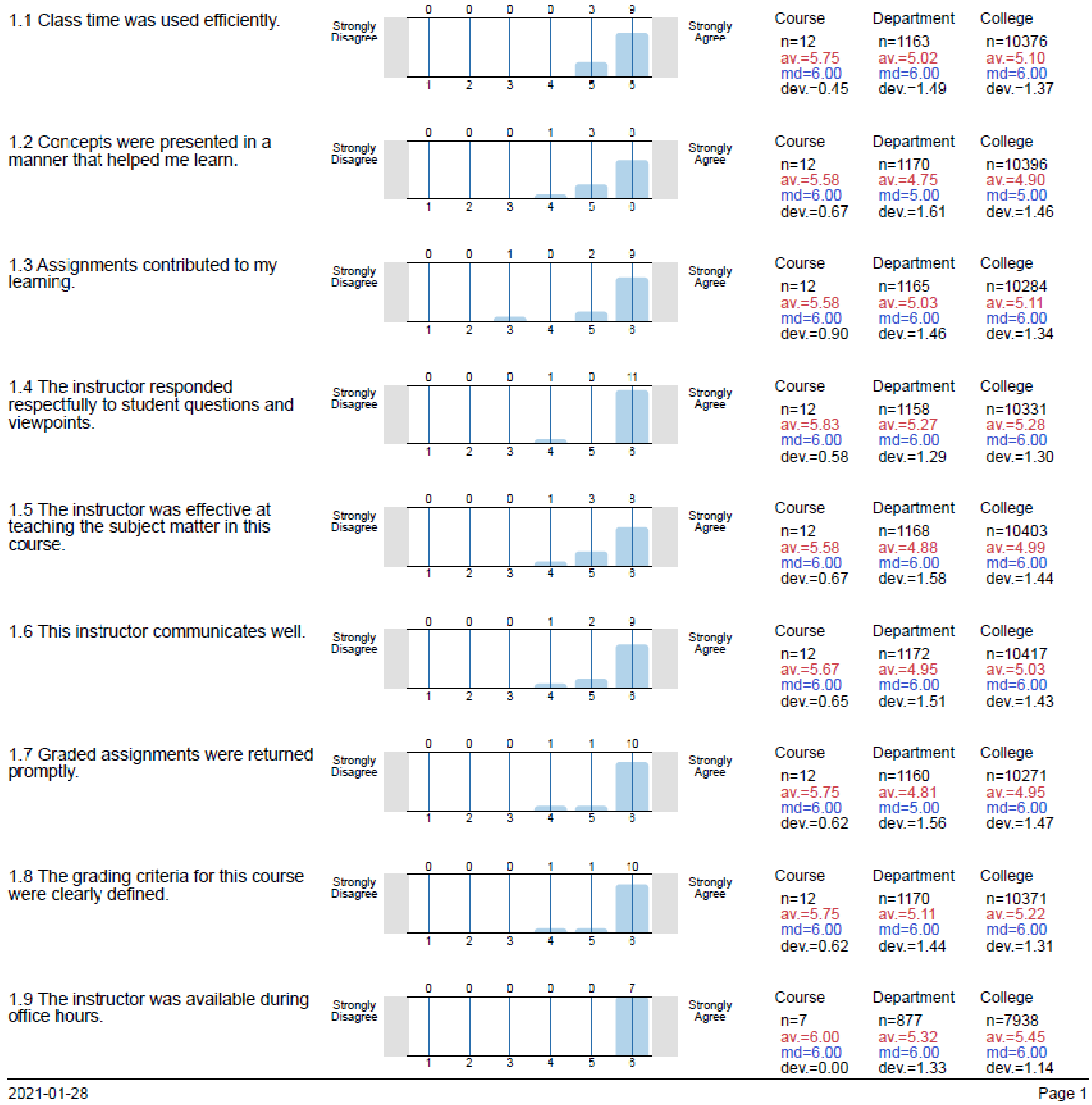
A valuable consideration regarding the benefit of the change that we've made to the remote EE laboratory courses is how well it addresses the desired course learning objectives. Consider the learning objectives listed below for an example course for senior level analog electronics II. The learning objectives for that course are:

> 1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
> 2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
> 3. an ability to communicate effectively with a range of audiences
> 4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
> 5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
> 6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
> 7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
> 8. Upon successful completion of this course students will have experience with the following circuits: opamp signal conditioning circuits, output stages to drive loads, broadband transistor amplifiers, differential pair transistor amplifiers, opamp active filters, feedback amplifiers, and signal generators.

The first objective focuses on *applying* engineering principles. This is where the myDAQ instrument excels in allowing the remote students to really apply the principles being taught in the class and not just relying on artificial simulations. The second objective also is focused on realistic application and so the myDAQ enables the students to do so in spite of studying remote from the university. The third objective concerns communication: The myDAQ might not be thought to directly address that, but then again it does. We find that the students communicate more during the remote Zoom sessions when they are each striving to get their laboratory measurements made while each student is operating their own myDAQ – and pointing out things to help other students use it correctly – than the students tend to be when they are required to only complete the exercises using circuit simulation software, which they can postpone . The fourth objective is not significantly impacted by the students' remote use of the myDAQ instrument. The fifth objective is promoted by use of the myDAQ for the same reason of encouraging active student engagement discussed above concerning the third objective. The sixth objective is better accomplished with remote use of the myDAQ instrument than without and only relying on circuit simulation. With the realistic measurement capability that the myDAQ provides the students are encouraged to do additional, practical experiments that the instructor deems to be of value related to the laboratory experiment at hand, such as connecting a speaker to an output stage amplifier. The experimental data carries more weight in the student's mind when it is an actual, realistic application rather than an artificial simulation. The real measurement data is easier to believe and make a realistic impression on the student. The seventh objective is also supported by the myDAQ instrument in a similar sense as discussed above for the former objective: appropriate learning strategies are certainly more *appropriate* when based on real measurements than on artificial simulation. The sixth and seven learning objectives essentially fulfill the intentions of a project-based learning curriculum such as that discussed by Zhang, et al.[8]

Learning assessment during cov-19 pandemic

Figs 2 and 3 below present the fall 2019 Student Perception of Teaching (SPOT) survey results for two of the first EE laboratory courses to involve remote student use of the myDAQ instrument loaned out by the university to the individual students. The SPOT surveys are collected from the students late in the semester before they receive their semester grades. Note that in both of these samples of SPOT survey results that the results below for the respective course (using the myDAQ) are higher in every category than both the department and college SPOT survey results (not all using myDAQ). Some limitations in using this SPOT data are that senior level courses, especially technical electives, tend to have higher scores, and a small course tends to have higher scores than one with a larger number of students.



Item	Strongly Disagree 1	2	3	4	5	6 Strongly Agree	Course	Department	College
1.1 Class time was used efficiently.	0	0	0	0	3	9	n=12 av.=5.75 md=6.00 dev.=0.45	n=1163 av.=5.02 md=6.00 dev.=1.49	n=10376 av.=5.10 md=6.00 dev.=1.37
1.2 Concepts were presented in a manner that helped me learn.	0	0	0	1	3	8	n=12 av.=5.58 md=6.00 dev.=0.67	n=1170 av.=4.75 md=5.00 dev.=1.61	n=10396 av.=4.90 md=5.00 dev.=1.46
1.3 Assignments contributed to my learning.	0	0	1	0	2	9	n=12 av.=5.58 md=6.00 dev.=0.90	n=1165 av.=5.03 md=6.00 dev.=1.46	n=10284 av.=5.11 md=6.00 dev.=1.34
1.4 The instructor responded respectfully to student questions and viewpoints.	0	0	0	1	0	11	n=12 av.=5.83 md=6.00 dev.=0.58	n=1158 av.=5.27 md=6.00 dev.=1.29	n=10331 av.=5.28 md=6.00 dev.=1.30
1.5 The instructor was effective at teaching the subject matter in this course.	0	0	0	1	3	8	n=12 av.=5.58 md=6.00 dev.=0.67	n=1168 av.=4.88 md=6.00 dev.=1.58	n=10403 av.=4.99 md=6.00 dev.=1.44
1.6 This instructor communicates well.	0	0	0	1	2	9	n=12 av.=5.67 md=6.00 dev.=0.65	n=1172 av.=4.95 md=6.00 dev.=1.51	n=10417 av.=5.03 md=6.00 dev.=1.43
1.7 Graded assignments were returned promptly.	0	0	0	1	1	10	n=12 av.=5.75 md=6.00 dev.=0.62	n=1160 av.=4.81 md=5.00 dev.=1.56	n=10271 av.=4.95 md=6.00 dev.=1.47
1.8 The grading criteria for this course were clearly defined.	0	0	0	1	1	10	n=12 av.=5.75 md=6.00 dev.=0.62	n=1170 av.=5.11 md=6.00 dev.=1.44	n=10371 av.=5.22 md=6.00 dev.=1.31
1.9 The instructor was available during office hours.	0	0	0	0	0	7	n=7 av.=6.00 md=6.00 dev.=0.00	n=877 av.=5.32 md=6.00 dev.=1.33	n=7938 av.=5.45 md=6.00 dev.=1.14

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Figure 2: Sample SPOT survey results for a junior-level EE laboratory course using myDAQ.

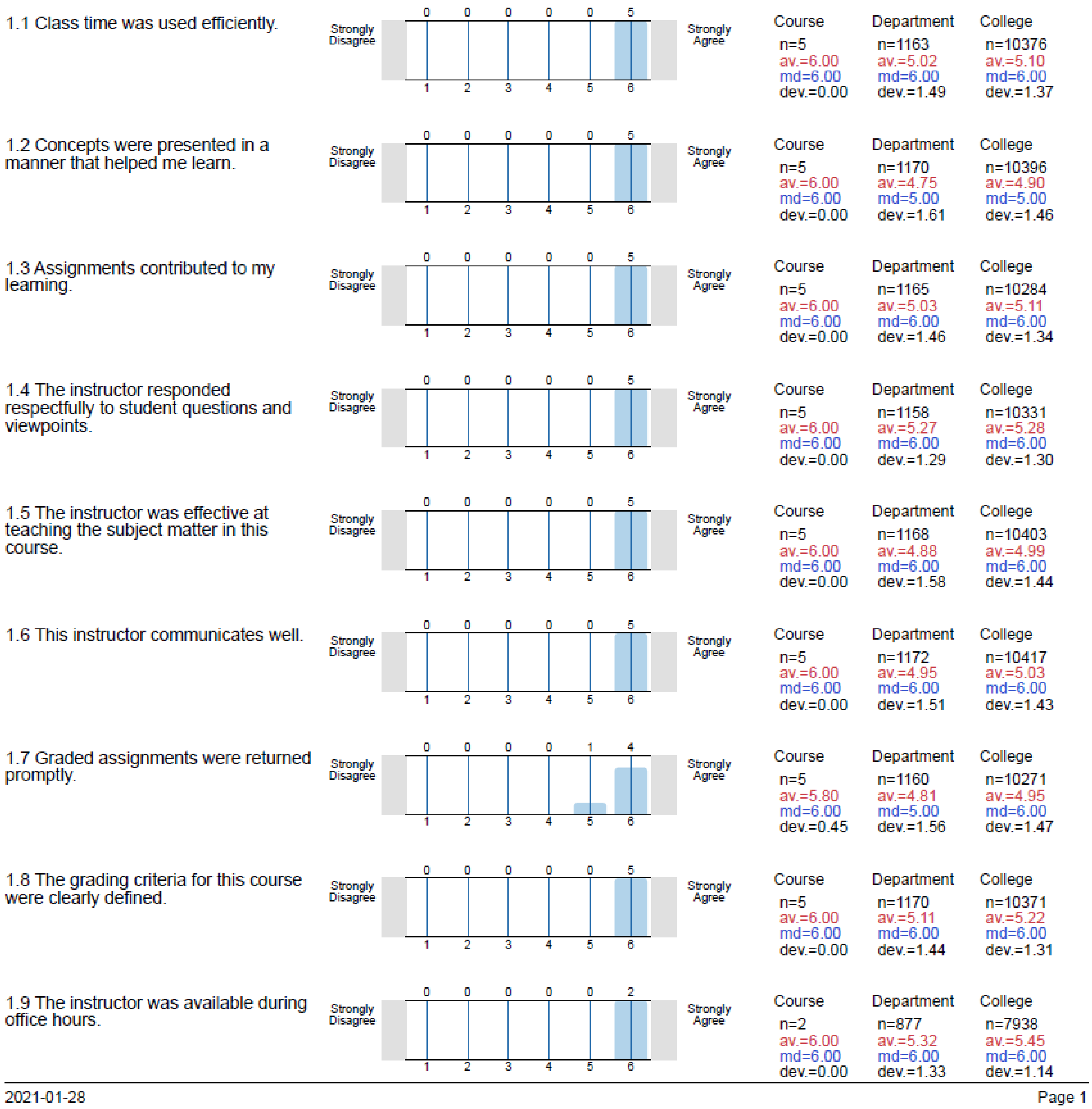

Figure 3: Sample SPOT survey results for a senior-level EE laboratory course using myDAQ.

Evidence that the students are suitably engaged in the laboratory courses involving remote use of the myDAQ also includes voluntary feedback via email to the instructor from students with comments such as, “Like other classmates have mentioned, the [pre-recorded] zoom videos [that] you have provided for us really help with the [myDAQ] lab [work].”

An audio recording of the fall 2020 EE430L senior level analog electronics II laboratory students volunteering their own, first-hand impressions of their use of the myDAQ is available at https://csulb.zoom.us/rec/share/Fxr2tcNRS_STzxGknfMmW3S_gth7Kve-4b4Q0jOCVqcWEN7b6JRF56EdDiDnWZLy.F-qZfdbYREbTHpSs with password =

KxMBCB#1. This discussion with the students, which is a summative assessment of their use of the myDAQ instrument, occurs in the recording starting at 00:06:00 through 00:24:00.

We have focused on being very responsive to the student feedback regarding the laboratory courses, especially now during the pandemic. It appears that the best enhancement to active student learning and positive assessment results is for the laboratory instructor to be as engaged as possible with the students both during office hours and the scheduled class sessions.

Conclusion

The fall 2020 laboratories went rather well and were deemed to have met the intended learning objectives in spite of the ongoing pandemic, with the EE laboratory students being engaged in their laboratory exercises with remote use of the myDAQ. At the end of the fall semester the students were asked for their impressions of using the myDAQ, and the majority of the laboratory students welcomed the use of the new instrument. No complaint about use of the myDAQ was received after overcoming a few software setup issues that some of the students encountered but were readily resolved. Students expressed appreciation of its special features such as the Bode Analyzer that automates the measurement of the frequency response of a circuit – a feature that the instruments in the university laboratories don't currently offer (unless the myDAQ is to be added). Student feedback concerning the myDAQ included the suggestion that the university also consider investing in the newer NI myRIO device. Guidance that we might offer to instructors intending to transition to a remote laboratory course would include reviewing the practical suggestions addressed in this paper such as having a backup non-VOIP audio conference line simultaneous with the Internet (Zoom) laboratory sessions. Be as engaged as possible with the students and make each remote laboratory session as fun as possible. Honor the students with patience; serve them with kindness; overlook their mistakes with lightheartedness; encourage only the truth; and try to be creative in leading them to answer their own questions themselves.

Overall this was one aspect of our university's effort to make additional effort in response to the pandemic in order to maximize the quality of professional skills that can be taught to the students to help them each pursue a successful career.

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