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Assessing the Impact of User Interface Abstraction on Online Telecommunications Course Laboratories

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ABSTRACT In this paper, we analyze the impact of user interface abstraction in remote telecommunications laboratories. We employ four interfaces, ranging from point-and-click to traditional in-lab interfaces, for students to interact with networking equipment. We then survey students following the completion of these laboratory exercises to assess the effect of the different user interfaces on the learning experience. Our analysis indicates a sweet spot in the amount of abstraction provided by the interface, with the Web-based rich interactive interface obtaining the most positive feedback from students.

INDEX TERMS Remote experimentation, eLearning, remote labs, user interface abstraction.

I. INTRODUCTION

Online courses are, increasingly, a vital part of university teaching, due to advances in eLearning technology and the desire to support a diverse population of distance-learning students. At the same time, the experimentation process is of fundamental importance for both undergraduate and graduate engineering education and research: physical experimentation directly underpins engineering education by providing students with the valuable experience of putting theory into practice. In the eLearning context, there is the need for remote laboratories and hands-on experimentation to reinforce the learning process.

To provide remote physical laboratories that can be accessed online via eLearning platforms, several components must come into play, such as testbeds and laboratory equipment able to be remotely manipulated, networking components to provide the communications between the eLearning platform and the testbed facility, and the interactive multimedia tools to interface the students to the remote lab.

There are several initiatives reported in the literature that provide rich, remotely accessible online lab experiences, through a powerful set of multimedia resources ([1]). These initiatives build user interfaces for students to interact remotely with physical components employed in laboratory experiments. It is key that the abstraction provided by those interfaces not obscure the students' perception of dealing with real facilities and conditions, as opposed to simply a simulated environment. The question we address in this paper is which user interfaces for online laboratories are effective in conveying the learning message without detracting from the real value of hands-on experimentation.

To provide answers to the above question, we have assessed student reactions to online labs that provide students with practical hands-on knowledge of telecommunications networks. In our course, students experiment with wireless communications and networks using three different high-performance testbeds, located in Belgium, Australia and Ireland. The remote lab materials associated with two of these testbeds provide different levels of interaction and abstraction, allowing students to remotely access the network testbed resources from web interfaces and command line tools. In contrast, students use the third testbed locally, to experiment directly with radio equipment. We assessed students' experiences through anonymous surveys performed at the end of each lab session, revealing the students' preferences and the skills they gained during the course.

Moreover, in order to perform a fair comparison among the different type of interfaces, we conducted some of the same experiments using different access interfaces, evaluating students' responses to each version of the same experiment. In this paper, we report on the results of the study described above.

II. RELATED WORK

During the last forty years there has been an evolution on the education-related tools used to enhance educational processes. Zawacki-Richter and Latchem [2] present a solid analysis of the education-related research outcome for the last four decades depicting a transformation from computer-based instruction education -during the mid seventies to mid eighties- to online learning in a digital age -during the last decade-, having experienced stand-alone multimedia, and networked computers as tools for collaborative learning during the nineties and early years of the new millennium. Nowadays, regarding laboratories, they can be grouped into traditional in-lab, virtual, and remote laboratories [3], [4]. Traditional laboratories situate the interaction of students with the lab equipment within the laboratory premises, while virtual and remote laboratories can be accessed, via internet, from different locations. Virtual laboratories are empowered by simulation software that provides students with a lab experience close to a real lab session [5]. Finally, remote laboratories enable remote access, through software interfaces, to real lab equipment in order to provide a real lab experience from a remote location. In both virtual and remote labs, the software interfaces that allow students to interact with the virtual or real equipment, respectively, is a key factor for the success of the learning outcomes and the lab experience in general [6]. Therefore, in this paper we focus on measuring the impact of such user interfaces in remote and in-lab laboratories in general, and the level of the abstraction of those interfaces in particular.

Diwakar *et al.* [7] study the trade-offs among technological aspects, such as testbed technology, processing capabilities, and user interfaces; and the pedagogical aspects, such as objectives of the lab and feedback methods, within the control systems domain. Authors analyzed a wide range of technologies for remote experimentation including Matlab, LabView, Java-based systems, and virtual labs. Their findings reveal that virtual labs were preferred by engineering students due to the web-based interfaces that virtual labs provided. Similarly, Lindsay and Good [8] present an analysis of the impact of lab interfaces and their audiovisual feedback on learning outcomes. These authors analyzed two types of laboratories: remote, and virtual labs, considering web interfaces for both labs, based on audio and video streaming from the equipment to enrich the students' remote lab experience. Moreover, authors compare such analysis with a previous work of them on traditional labs [9]; such comparison reveals the preferences of students towards a rich audiovisual web-based interface.

Tsihouridis *et al.* [10] evaluate the effectiveness of remote labs in comparison to physical labs, including the interfaces as a factor. The authors applied questionnaires for the assessment, finding that with regard to conceptual understanding, remote laboratories have a similar impact on students as physical laboratories, highlighting the importance of the user interfaces in remote labs to provide a close experience to a real lab. Similarly, Marques *et al.* [11] emphasize the feeling of *immersion* in remote labs as indispensable. The authors, within an engineering laboratories context, have analyzed several works empowered by Virtual Instrument Systems In Reality (VISIR) systems, a remote laboratory for wiring and measuring electronic circuits [12], [13], from teachers' and students' perspectives considering usefulness (pedagogical values) and usability (technical issues) factors and in terms of learning achievements.

An interesting study of the impact of software-based interfaces in the design of remote labs is presented by Garcia-Zubia *et al.* [14], where authors evaluate the most appropriate software at the client and server side to enable the WebLab-Deusto lab, a remote lab system for high school physics labs. Authors also survey students, assessing their experience with the different versions of the lab, which vary from a desktop application to a web application implemented with Ajax programming language. The outcome clearly favors web application labs due to the ease of use provided by the interface.

Jourjon *et al.* [15] demonstrated the effectiveness of their remote lab and its web-based interface through an evaluation from the students' point of view about learning perception and interface appreciation. Overall the students rated this approach well for understanding general and specific subjects from the lecture. Moreover, Shanab *et al.* [16] evaluate the students' perception of different laboratories including augmented reality (based on remote access), virtual, and hands-on, and their interfaces, concluding, based on surveys, that the virtual and augmented labs were more effective for enhancing students' understanding of the lectures.

As aforementioned, our study presents an evaluation of the impact of remote labs, using different interfaces, on students and the relationship between the level of abstraction and usability of each type of user interface used and the students' satisfaction level. Our work extends beyond existing works, such as the ones proposed by Lindsay and Good [8], [9], by focusing on the level of abstraction and usability of interactive interfaces. Last, but not least, we take into account and acknowledge the fact that technology-enhanced learning techniques, relying on the use of computing devices such as tablet, laptops, and PCs, already impact on the students' learning abilities, and in the learning process in general [17].

III. METHOD

In this paper we assess the impact on engineering students of the level of abstraction of the interfaces employed to access and to interact with network testbeds. We define level of

TABLE 1. Wireless networks and communication course syllabus.

Week	Lecture hours	Lab hours	Experimentation	CS2013 Knowledge area	Interface type
1	2	2	TCP/IP networking & HTTP protocol	Networking and communication	Web-based click-and-point
2	2	2	End-to-end data reliable transfer mechanism	Networking and communication	Web-based click-and-point
3	2	2	TCP congestion control	Networking and communication	Web-based click-and-point
4	2	4	WLAN infrastructure - performance evaluation	Networking and communication	Command line
5	2	3	WLAN ad-hoc - performance evaluation	Networking and communication	Command line
6	2	3	802.11 QoS	Networking and communication	Command line
7	2	6	Reinforcement for weeks 4, 5 and 6	Networking and communication	Web-based rich interactive
8	2	4	WLAN authentication, WEP security	Information assurance and security	Command line
9	2	2	WLAN WPA security	Information assurance and security	Command line
10	2	2	OFDM signalling	Systems fundamentals	Traditional in-lab
11	2	2	Dynamic spectrum access	Networking and communication	Traditional in-lab

abstraction as the degree to which the interface disassociates the user interaction from the physical testbed. The user interfaces that we have evaluated range from web-based to traditional in-lab physical interfaces, which were used for remote and in-lab experimentation. In this section we describe the features of those user interfaces, the learning context where the labs were deployed and evaluated, and the assessment tools that we used in order to evaluate the impact on students.

A. LEARNING CONTEXT

The learning context is an Electrical and Electronic Engineering Master's level course on wireless networks and communications, which has both theoretical and practical components. In this course students are introduced to practical hands-on networking experimentation through different laboratories, reinforcing the lectures. Students apply the concepts they have studied theoretically through implementation and real experimentation on wireless communications and networks, including software-defined radio, wireless local area networks, and network protocols. Students experiment with wireless network testbeds located in Australia, Belgium and Ireland, using diverse user interfaces that imply distinct levels of interaction and abstraction.

For this course, we have followed the IEEE/ACM CS2013 joint curriculum for computer science engineering, proposed by the ACM/IEEE-CS Curricula Steering Committee [18], which includes and extends to electrical engineering and other engineering disciplines. The content of the course was designed following the high-level goals of the CS2013 Networking and Communication knowledge area, which are: i) thinking in a networked world, ii) continued/linked advanced study, iii) principles and practice interaction. We created online educational material structured in mini-courses or modules containing defined portions of the CS2013 Body of Knowledge. That way, modules can be reused by different institutions. Table 1 presents the syllabus of the course encompassing theory and experimentation from a top-down approach [15], as well as the user interface applied to deliver the experimentation. The description of such interfaces can be found in Section III-B.

B. USER INTERFACES

This study assesses the level of abstraction of the different user interfaces used by the laboratories and its impact of engineering students. We classify such user interfaces as shown in Figure 1.

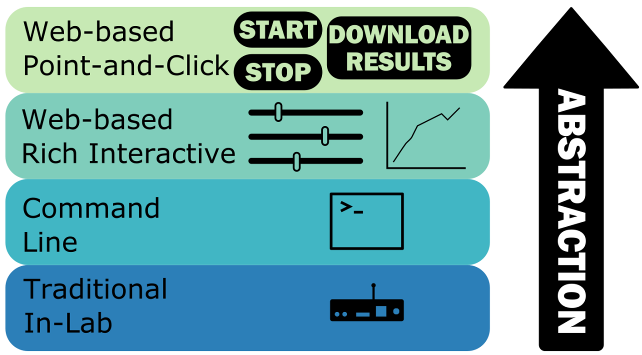

FIGURE 1. Level of abstraction of the user interfaces used for experimentation.

- *Web-based point-and-click interface.* A web-based point-and-click user interface allows experimenters to interact with the testbed in a supervised manner, encapsulating a number of options and operations. The interface provides forms where experimenters can set parameters and launch experiments to later collect the results. The interface translates the input from the web forms into commands for the testbed equipment to launch the experiments. Then the results, collected as sql datasets, are available to be downloaded by the experimenters. Figure 2(a) shows an example this type of interface.
- *Web-based rich interactive interface.* The web-based rich interactive interface contains widgets to control and set input parameters, and to display experimentation output in real time through a set of dynamic plots. This interface can be used within eBooks or imported to different Learning Management Systems (LMSs). Also, the interface can be displayed in a wide range of computing devices. This type of interface is shown in Figure 2(b).

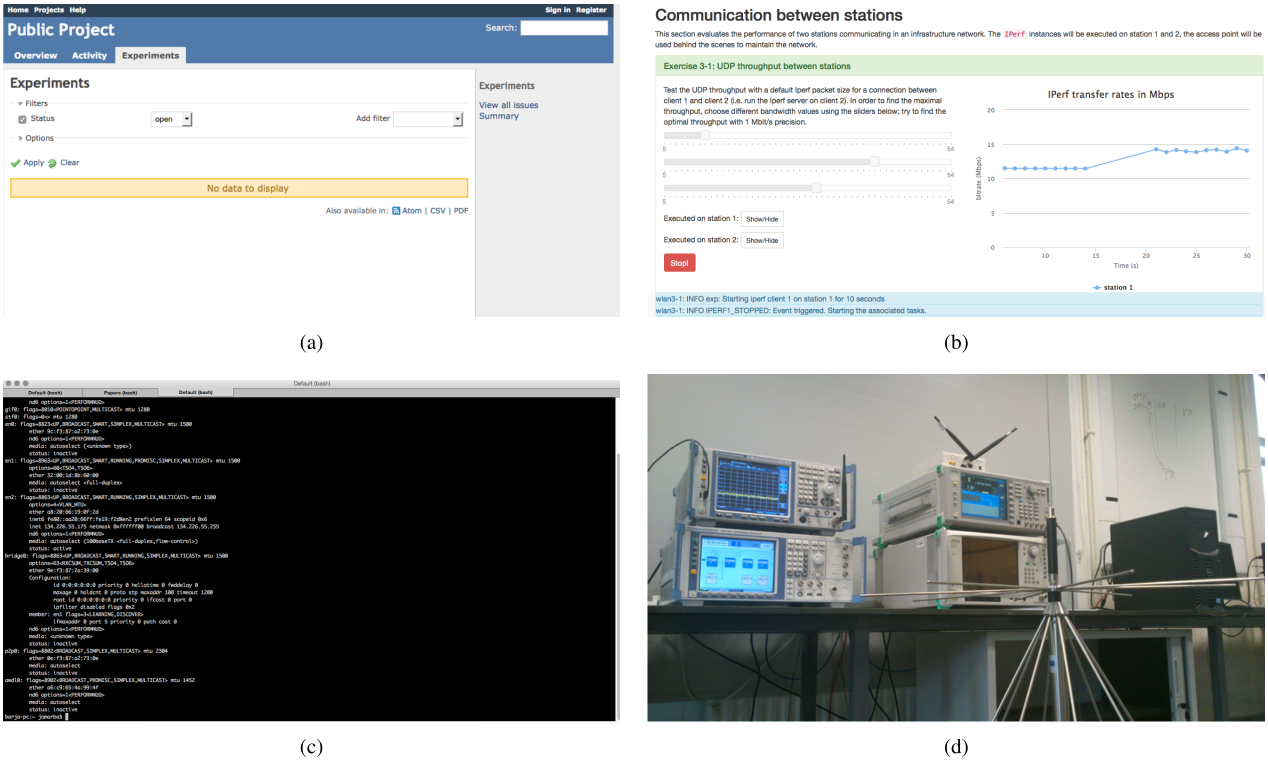

FIGURE 2. Different lab interfaces evaluated. (a) Web-based point and click. (b) Web-based rich interactive. (c) Command line. (d) Traditional in-lab.

- *Command line interface.* Command line allows students to remotely access the testbed and perform experiments. Experimenters type commands to configure the equipment and to run experiments. In this type of interface there are no widgets that facilitate the control of the input or display the results; the results either can be saved to log files or directly printed to text output, as shown in Figure 2(c).
- *Traditional in-lab interface.* This approach allows experimenters to interact directly with the equipment but requires that experimenters be physically located in the laboratory facilities. Figure 2(d) presents the equipment used in the in-lab experimentation.

C. INSTRUMENTS

To assess the student perception of the user interfaces we asked students to complete an anonymous survey, as a formative assessment activity and as an online assessment to assess both level of satisfaction and understanding of students [19], [20], following each laboratory exercise. These surveys, administered via survey monkey,[1] collected the subjective opinion of the students with regard to the five statements listed below. Each question focused on a particular aspect of the student's laboratory experience. Questions were structured as statements for which students were asked to indicate their agreement on a five-point likert-type scale [21], consisting of the levels: strongly disagree, moderately disagree, neutral, moderately agree, and strongly agree. Student responses to these questions provide the basis for our examination of the impact of the user interfaces employed in laboratory exercises on student experience.

Survey statements:

1) The lab experiments helped you to understand the concepts taught in the lecture.
2) The interface (web or command-based) reduced the difficulty of the lab.
3) You were always aware that you were performing real experiments using network equipment located in other facilities around the world.
4) The experimentation helped you to self-assess your progress in the course.
5) You would use the testbed facility in the future, if you have access to it.

The analysis of student responses to the above questionnaire is presented in Section IV.

IV. RESULTS

A total of 16 students were enrolled in the course, performing the different labs in two person teams. The lab duration varied from 2 to 3 hours for a total of 14 sessions, resulting in more than 1300 networking-related experiment executions.

The student responses to the survey questions provide insight into the role of abstraction in experimentation interfaces. Unsurprisingly, we find that abstraction offers a potent

[1] www.surveymonkey.com

means of tempering the difficulty of experimentation by exposing only the most relevant portions of the testbed facility to the students. More interestingly, however, we find that an over-abundance of this abstraction quickly degrades the student experience. In fact, in several cases, it is clear that no abstraction at all is vastly superior to excess abstraction. Therefore, while abstraction in experimentation interfaces certainly contributes to positive student experiences, this abstraction must be balanced to maintain the students' connection to the underlying equipment.

We grouped surveys for each individual laboratory exercise according to the interface employed for the exercises in question, as described in Section III-B. The proportion of responses corresponding to each agreement level from this grouping for each question is displayed in Figure 3. Furthermore, these figures display the overall levels of agreement and disagreement for each question and interface. Together, this visualization of student responses provides an indication of the impact of the user interface on student responses.

Examining Figure 3(a), we can see that the students generally considered the labs to be a helpful experience with regard to their understanding of the subject matter. This result is, on the whole, in line with prior findings that link experimentation to a furthering of understanding. In fact, only the most abstracted interface, the web-based point-and-click interface, failed to elicit a 90% agreement to the first survey question. This marked difference in student responses leads to our finding that too much abstraction has a detrimental effect on student experience. In this particularly case, we see that the loosening of the connection between students and equipment degrades the value of experiment in terms of student understanding of the underlying material.

Figure 3(b) displays students' feedback on the impact of the user interface on the difficulty of the laboratory exercise. More than any other question, the response to this survey question highlights the non-monotonic relationship of interface abstraction and improvement of student experience. Naturally, the student responses indicate a increasing reduction in laboratory difficult as abstraction increases, until a sharp corner is reached. The first portion of this evolution, the period of positive correlation between abstraction and difficulty reduction, follows naturally from the purpose of abstraction in interfaces as a means to hide extraneous detail and focus the students on meaningful aspects of the experiment. However, the sharp downturn in responses indicates that there is a limit to the value of hiding details in favor of exposing only the relevant aspects to a student. At some point, the limitation of options to the student inhibits her ability to explore the concept in her own preferred manner. Here the focus on limited options becomes a hindrance to the learning process.

Figure 3(c) assesses the students' awareness that they were performing real experiments using remote facilities, as opposed to a simulated environment. Overall, the responses reflect that students were consistently aware that remote facilities were in use for the laboratory exercise, with two exceptions. When the web-based point-and-click interface was used, while most students indicated their awareness that experiments were being conducted on real hardware, the portion that indicate the lack of such a connection is especially significant because students were informed that they were performing experiments on top a remote facility, prior to each laboratory exercise. For exercises conducted when students were in-lab, the small uptick in negative results may well be linked to confusion over the question's reference to remote facilities. Once again, an excessive amount of abstraction in the user interface appears to undermine the connection to real events, even if explicitly stated by the instructor, ultimately degrading value to the student.

Figure 3(d) illustrates the impact of the user interfaces employed during laboratory exercises on the students' ability to self-assess progress during the course. In terms of the influence of the user interface, this question investigates the feedback made available to students that lets them assess their understanding of the topic at hand. With the singular exception of user interface 1, students had a high opinion of the interactivity offered by the user interfaces in support of self assessment activities. We find that the limitations associated with abstraction beyond some threshold are detrimental to the operation of the student, focusing, in this case, on the process of self-assessment. Abstraction at this level disconnects the student from the experiment, hiding the details that allow students to perform self-assessment.

Finally, Figure 3(e) shows the eagerness of students to use the test facilities in the future. This question explores students' impressions of the facilities employed in laboratory exercises, as experienced through the lens of each user interface. Within this regard, this figure captures the students' overall impression of the user interfaces provided by each facility. Here we note variability that resembles that found in Figure 3(b). As seen in the above figure, student agreement increases with increasing abstraction until some point, after which we see a steep decline in student interest in the facility. As elucidated throughout all the student responses, the detail hiding associated with a high level of abstraction in the user interface also appears to hide the value of a facility from the student perspective.

Figure 4 displays the distribution of student responses to each survey question, grouped according to the user interface employed in the laboratory exercise. For the purposes of these plots each response was assigned a numerical value, reflecting the level of agreement indicated by the student; in this scheme -2 corresponds to strong disagreement and 2 corresponds to strong disagreement, with other levels of agreement represented as unit steps between these two extremes. The top of each box marks the third quartile, which splits the highest quarter of the responses from the lowest three quarters. The bottom of the box indicates the first quartile, which splits the lowest quarter of the responses from the highest three quarters. The center red line identifies the median response. The upper whisker shows the highest response value less than the third quartile plus one and half times

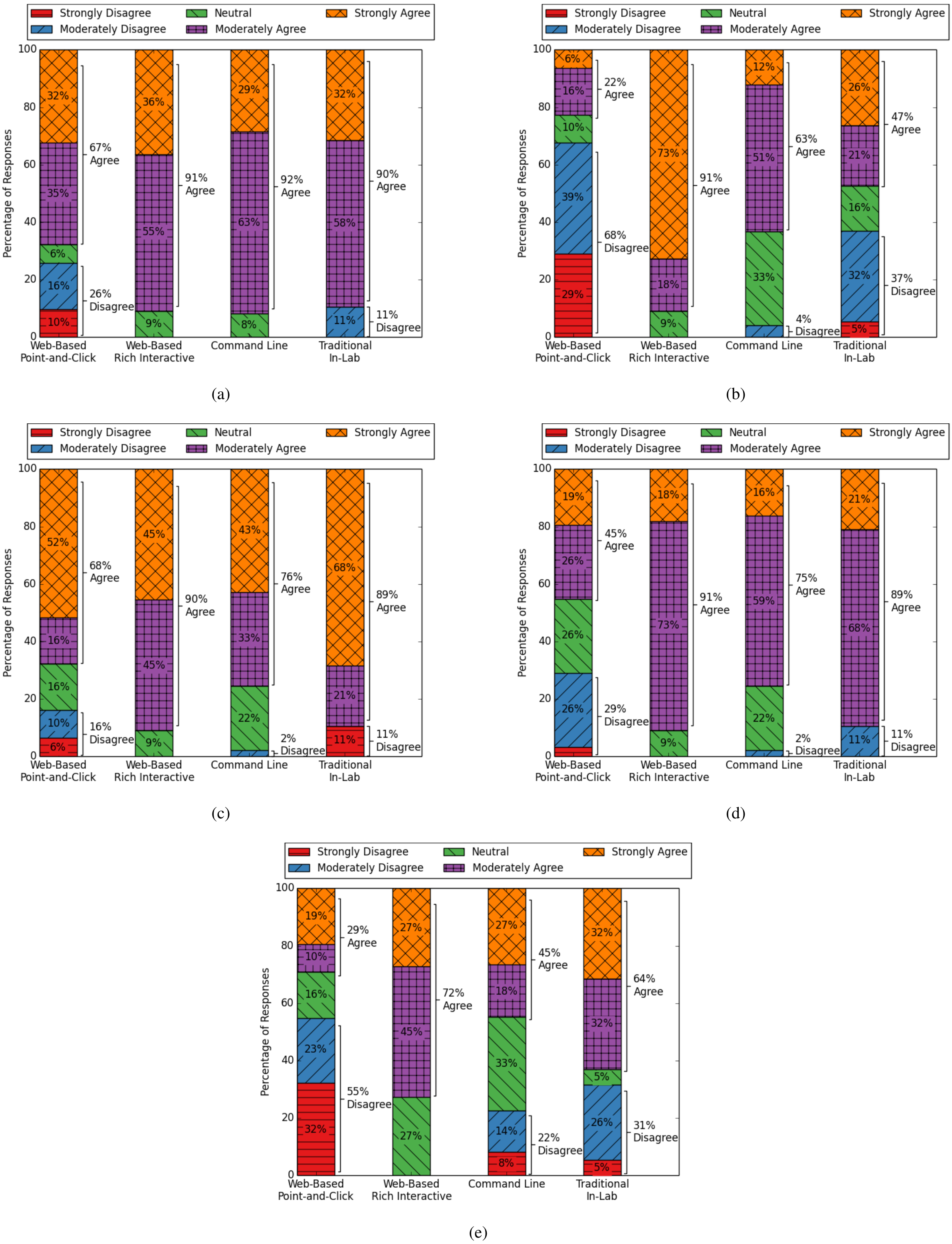

FIGURE 3. Student survey responses in (a) question 1, (b) question 2, (c) question 3, (d) question 4, and (e) question 5 for each user interface.

the distance between the first and third quartiles. The lower whisker shows the lowest response value within the first quartile minus one and half times the distance between the first and third quartiles. All responses outside of the whiskers, marked as crosses, are considered outliers. In this way, this set of plots displays the consensus, or lack thereof, of the student opinions for each question with respect to each user interface.

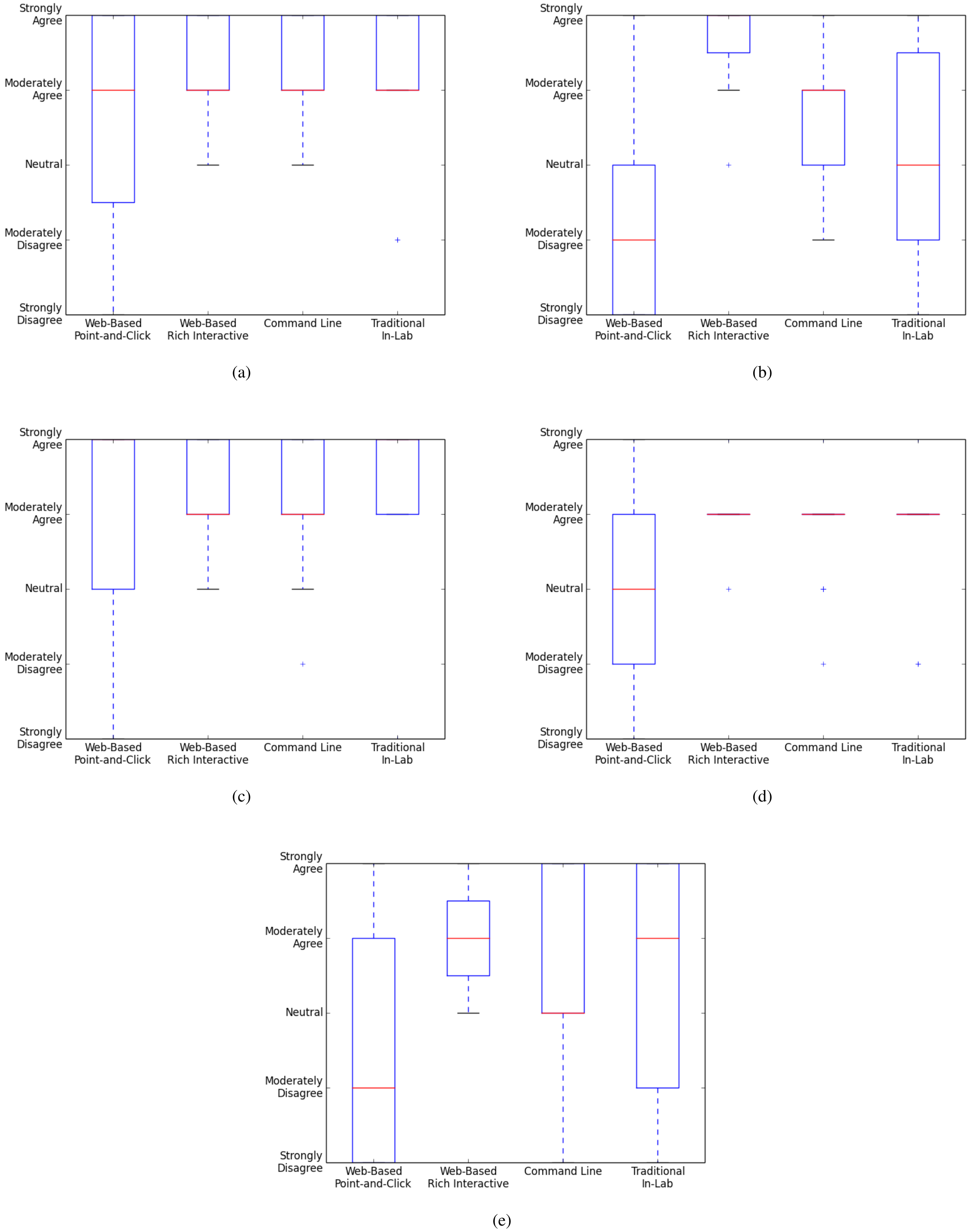

FIGURE 4. **Box plot of student survey responses in (a) question 1, (b) question 2, (c) question 3, (d) question 4, and (e) question 5 for each user interface.**

Examining Figures 4(a), 4(c), and 4(d), we find that student opinions are generally favorable of the user interfaces employed for laboratory exercises. Additionally we see in these figures that students' opinion regarding the web-based point-and-click interface is typically lower than the other interfaces. Overall we see that students tended to agree with regard to each of these questions, sometimes remarkably so.

The other two questions exhibited much higher variability, as illustrated in Figures 4(b) and 4(e). In both of these questions, students exhibited a consistently high opinion of the web-based rich interactive interface and somewhat favorable, although much more broadly spread, opinion of the command line-based interface. Students did not exhibit consensus with regard to the remaining interfaces, more often favoring the in-lab experience to the web-based point-and-click interface. This spread of responses for the extremes of abstraction considered in this study indicates that, while some students could certainly gain value from these edge cases, the level of abstraction must be balanced to provide a uniform educational experience.

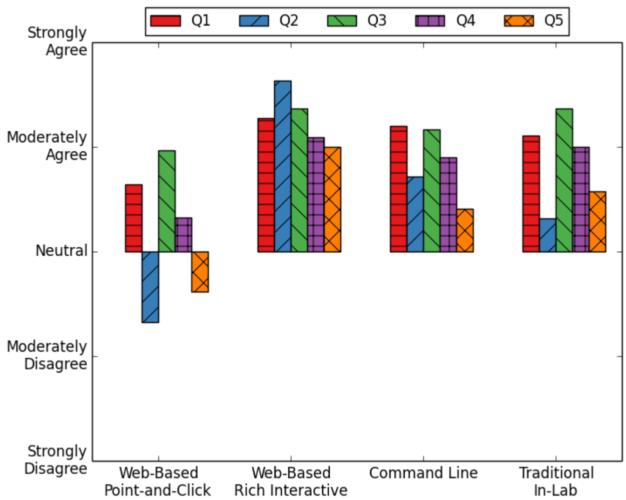

FIGURE 5. Mean student survey response in each question for each user interface.

Figure 5 displays the mean response of students in each question, grouped according to user interface. This figure applies the same numbering methodology employed for the box plots of Figure 4. This figure provides a general characterization of each user interface. The first, and most abstracted, user interface, the web-based point-and-click interface, was considered by students to be the worst of the group, with especially poor performance in easing laboratory exercise difficulty and eliciting interest in further use of the associated remote facility. The second user interface, the web-based rich interactive interface, achieved the best balance of abstraction and was regarded by students as providing the best experience with regard to every question. The third user interface, the command line-based interface, reached the second position only in support for development of understanding and ease of use, but was relegated to third position by students with regard to the other three questions. The response to the in-lab interface indicated that low abstraction user interfaces provide significant connection to real equipment, ability for self-assessment, and motivation for facility reuse, primarily at the price of ease of use.

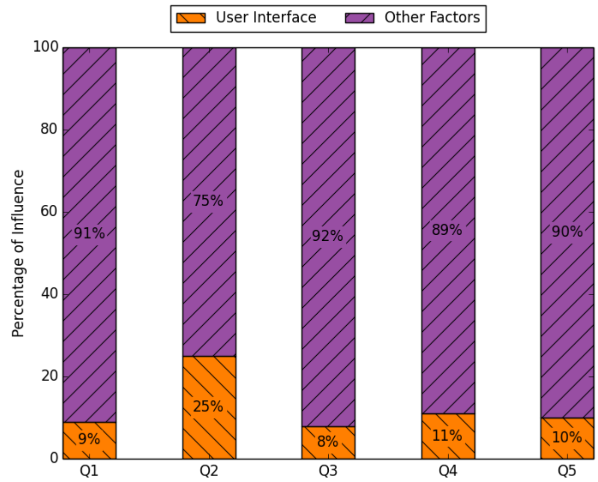

FIGURE 6. Influence of user interface on responses to each survey question.

V. DISCUSSION

We have analyzed the impact of different types of user interfaces on the students' perception of the remote labs. However, we acknowledge the fact that remote laboratories, and elearning systems, are complex systems, where several learning components and learner factors come into play to successfully deliver the desired message and learning outcomes. These learning components include the curriculum design, structure of the learning activities, relevance of the chosen interface technology, didactical and pedagogical approach, and effective time management [22], while the learner factors include epistemological beliefs, approach to learning, and attitudes towards technology use [23]. Therefore, we calculated the *uncertainty coefficient* [24] to analyse the relationship between student responses and the user interface used in each laboratory exercise. Conceptually, the uncertainty coefficient indicates the proportion of information in one quantity that directly reflects some other quantity. In this case, we use the uncertainty coefficient to quantify the impact that the user interface had on the student experience with regard to the questions in the survey, described in Section III-C. Mathematically, the uncertainty coefficient is calculated as the mutual information between the user interface and the subsequent student response, normalized by the entropy of the user interface. Equation 1 presents this calculation in terms of the probability of the use of a particular user interface, $P_I(i)$, the probability of particular student response, $P_S(s)$, the joint probability of a user interface and student response, $P_{I,S}(i,s)$, and the conditional probability of the use of a user interface given a student response, $P_{I|S}(i|s)$.

$$U(I|S) = \frac{-\sum_{i,s} P_{I,S}(i,s)\log_2 P_{I|S}(i|s)}{-\sum_{i} P_I(i)\log_2 P_I(i)} \quad (1)$$

Figure 6 summarizes the findings of the uncertainty coefficient analysis for each question. As is clear from this figure, the user interface is only one of several significant factors that influence the student experience; others may include: remote facility capabilities, expected grade, student feelings about the lecturer or course, or student interest on the topic as per suggested by the ACM/IEEE-CS Curricula Steering Committee [18]. Note that the subjective nature of the questions also impacts the influence of the user interface, as represented by the uncertainty coefficient, since the student's interpretation of the question or the meaning of 'strongly' or 'moderately' also impacts the response selected. In fact, the user interface is one of the only elements in full control of the educator; as such, the determination of the impact of the user interface provides insight into a rare aspect of control over the experience of students.

Our findings about the web-based rich interactive interface reinforce the use of technology such as the FORGEBox framework, which is a framework produced by the FORGE project[2] for developing and deploying remote experimentation on high-performance testbeds [25]. FORGEBox is a component that interconnects and hosts learning interactive content with federated resources across Future Internet Research and Experimentation (FIRE) testbeds,[3] offering a set of services that provide interactivity with the remote resources through the usage of web-based rich interactive interfaces empowered by widgets. Learning Management Systems, eBooks, and any future element that wishes to consume FORGE content, can either discover and integrate web reference points of widgets into their courses or adopt FORGE lab course descriptions as offered by the FORGEBox platform. A running instance of FORGEBox is located at `www.forgebox.eu/fb`, currently offering 40 course modules with several interactive parts covering topics on advanced networking, wireless networks and FIRE facilities usage.

VI. CONCLUSIONS

In this paper we analyse the impact of user interface abstraction on the experience of students with regard to educational experimentation. In the course of this analysis, we discuss four interfaces at different levels of abstraction employed in the support of laboratory exercises. To support our analysis, we have surveyed students following their completion of these laboratory exercises to determine the impact of the mechanisms used on their education.

We examine trends in student responses, finding that abstraction provides a useful methodology for enhancing student experience; however, too much abstraction of the experimental interface may obfuscate the physical testbed facility capabilities and operation. Thankfully, our analysis indicates the existence of a balance point of abstraction for student experimentation that is free from any such penalties. Moreover, we find the web-based rich interactive interface approaches this sweet spot of abstraction in all aspects considered here.

In the future, we intend to gain more insight into students' interactions, by developing and applying learning analytics technologies into the web-based rich interface. Widgets will be able to register different actions of the students and collect such data for further analysis, thus improving the quality of the assessment.

[2]www.ict-forge.eu
[3]www.ict-fire.eu

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