An Examination of the Personal Technology of Students in STEM Disciplines

Rob Elliott, Ed.D.
Computer and Information Technology
Indiana University Purdue University Indianapolis (IUPUI)
Indianapolis, Indiana
elliott@iupui.edu

***Abstract*—As more instructional materials are delivered electronically – particularly within courses in STEM fields – students at institutions of higher education (IHEs) are increasingly expected to be equipped with personal technology that allows them to interact with their academic coursework. Few IHEs directly provide that technology to students, which leaves the students themselves responsible for the selection and purchase of these critical computing devices. The result is that students utilize a wide variety of devices for their academic work – some of which may not meet the expectations of the institutions, instructors, and instructional designers who supervise the selection and implementation of the platforms used to deliver course content. This study will answer the following research questions:**

1) **What computing devices do higher education students in STEM programs own or extensively use?**
2) **What are the barriers higher education students in STEM programs have faced with regards to using their personal technology for coursework?**

This paper describes a mixed-methods study focusing on students at a large statewide university system in the midwestern United States. The results show that students generally have access to computing devices that allow them to engage in their academic work, but frequently encounter challenges in accessing or using their course materials on the devices they own. Ownership of computing devices varies based on several demographic categories, which results in an immediate divide between subgroups of students. The challenges encountered by students include an inability to perform their academic work on the device of their choice, insufficient computing resources to complete their expected activities, and instructional designs that are sometimes incompatible with the devices students have available.

This study hopes to inform the selection of digital platforms used to deliver academic content in courses frequently taken by students enrolled in STEM programs. Further, the study should provide an insight into the students' computing capabilities so that these factors can be considered during the instructional design and implementation of content delivery platforms.

***Index Terms*—Educational technology, Learning technology, Computer-based instruction, Technology studies**

I. Introduction

The digital divide is often – and incorrectly – thought of as a binary classification of those who have computing devices and internet access and those who do not [1]. Additional work has proposed several levels of digital divides that describe varying challenges to access and application of internet and communication technologies (ICTs) by individuals [2]–[4]. Studies of the digital divide describe a fluid, circumstance-driven environment in which populations experience computing and internet access quite differently even if, on the surface, they appear to have similar levels of access [2]. For students in institutes of higher education (IHEs) in the United States it is widely assumed that the first-level digital divide – that of access to the internet and internet-enabled devices – is generally ameliorated due to the high levels of device ownership and opportunities to go online [5]. However, some groups of students may have less access to computing resources, which can put them at an disadvantage academically [6]–[8].

Computing resource access concerns may be of even greater impact for students in STEM disciplines, as those courses have higher trends of digitalization of coursework and computer-based academic activities [9], [10]. Thus, students in STEM courses may be more reliant on internet connectivity and the use of computing devices to successfully meet their academic objectives. Research shows that STEM students use varying combinations of devices to accomplish academic work [11] and that their patterns of computer ownership can differ from students in other disciplines [12]. Further, differing levels of computer access for some demographic groups could negatively impact any diversity, equity, and inclusion (DEI) efforts that are proposed in those disciplines [13]. Kimmons [14] notes that there is a gap between "...what is being researched and what is being used..." (p. 805) and notes that few studies on educational technology deal with broader social issues such as accessibility and DEI concerns.

This mixed-methods study examines the patterns of ownership of computing devices and peripheral accessories among students enrolled in STEM programs at a large, multi-campus university in the midwestern United States in an effort to paint a broad picture of the technology students use in their everyday academic work. The study also includes demographic breakdowns that should reveal any differences in the technology used by different groups of students. Students participated in surveys and focus groups to detail their personal computing ecosystems, how their life outside of the university impacts those ecosystems, and the computer-related challenges they have encountered when trying to conduct academic activities for their courses. Specifically, this study answers the following research questions:

1) What computing devices do higher education students in STEM programs own or extensively use?
2) What are the barriers higher education students in STEM programs have faced with regards to using their personal technology for coursework?

The results of this study are meant to inform instructors, instructional designers, and the technology decision-makers at IHEs about the technical resources available to their students in STEM disciplines. Understanding the environments in which students conduct their academic activities may help those stakeholders select pedagogies and technological tools that conform to the technology available to students.

II. Literature Review

Technology has become pervasive in higher education and is an area of much interest. Studies that investigate a particular feature or function of a technology as it relates to learning will include some detail of the students' personal device ownership, but detailed ownership statistics are not the focus of the study [15], [16]. EDUCAUSE [17], a higher education information technology advocacy group, has conducted an annual study of students and information technology since 2004 [18], but their reports are centered around key findings rather than raw results, which limits their ability to be used as a foundation for other studies. Riesdorf, et. al., [8] notes that "...research on laptops in university settings has mostly focused on uses and classroom performance...rather than laptop *ownership* and overall college performance" (p. 928). Information about student access to technology is an important factor in the decision-making process behind the adoption of learning technologies. Understanding ownership patterns assists in analysis of the digital divide within a population [2] and the performance of students who are dependent on the use of technology for academic success [19].

As noted previously, the digital divide is also a topic of much study. Rather than a simple binary classification, study of the digital divide has grown to encompass three somewhat fluid levels with different types of impacts [1]. These levels can be described as 1) material access to devices and connectivity, 2) the digital literacy required to use these devices, and 3) the application of digital literacy skills to accomplish specific outcomes [8]. Obviously, these levels are tightly interwoven but it is readily apparent that the first level is foundational to the second and third. Institutes of Higher Education (IHEs) have invested in the infrastructure of connectivity and devices for student use, which affords access to students who are able to benefit from these resources — but many students are transient and have residences and jobs away from campus. And previously unheard-of situations like the transition to emergency remote teaching in March 2020 [20] left some students without the connectivity or equipment needed to engage in their academic work [21]. Therefore, even the first level of the digital divide can hardly be removed from consideration when evaluating technologies for student learning.

Kukulska-Hulme and Traxler [22] state frankly that "(e)ducation is no longer designed for a group of learners situated in a defined context; rather teachers face the challenge of designing for individuals who engage in their own learning, through their own devices, from their own settings, and on their own terms" (p. 1). The increasingly fluid nature of education — primarily, although not limited to, higher education — is made possible because students can engage with their academic work regardless of time or place [23]. This phenomenon is also possible because an increasing amount and wider variety of traditional academic materials are being delivered digitally to students [24]. The transduction of information from physical to digital forms is commonplace [25]. Thus, students are dependent on access to computing devices for the successful completion of their academic work [8], [26].

Digitalization of learning materials is primarily facilitated by a Learning Management System (LMS) — the implementation of which is nearly universal at IHEs in the United States [27]. 88% of faculty used an LMS even prior to the transition to online course delivery due to the COVID-19 pandemic. Instructors primarily use the LMS for the dissemination of academic content to students [28], [29], which can include texts, handouts, instructional videos, discussion boards, assignments, and quizzes or exams [30]. An LMS facilitates the transfer of digital course materials between a faculty and student (and vice-versa) with the intent of providing more control to the learners by affording them more flexibility in the time and space where they engage with the content [31]. However, studies demonstrate that faculty and students are using the LMS differently, and that instructors are designing their courses with a computer-first perspective while students are engaging with the LMS on a wider range of devices, including mobile phones [28], [32].

Students are using an increasing number of types of devices for academic work, including smaller mobile devices such as tablets and phones. This pattern is not limited to students who have fewer devices available to them — although a correlation exists [33], [34]. Students with access to a wider array of devices appear to be selective about the specific activities in which they engage on each device family [35]. However, because students are using a variety of device types, some have encountered difficulty with educational technologies that may have been built with specific computing environments in mind [28].

An examination of computing devices used by students would be incomplete if it examined only the devices themselves. Individuals use a wide range peripherals — including printers, input devices, and monitors — while engaging with their computers. Although statistics show that anywhere from 90-98% of students have a laptop computer [5], the quality of those devices can vary and the environment in which they are used may also factor into their ability to help students perform academic work [23], [26]. Some studies have shown benefits from having multiple screens available that allow students to multitask or reference materials while learning [36], [37]. A study by Van Derusen and Van Dijk [2] shows that access to computing peripherals varies based on several demographic

variables, including income and age.

III. Methods

The first phase of the study was conducted by anonymous survey at a major public university system in the US Midwest with over 90,000 students. The university has seven physical campuses (including a core residential campus, a large urban semi-residential campus, and five regional campuses) and a slate of exclusively online programs. All students in an online program are also assigned to one of the seven campuses. The survey included a set of demographic questions (including their major, age, and enrollment status) to ensure that the analysis is representative of the student body as a whole. Invitations were made via emails to university-assigned email addresses and delivered through the Qualtrics survey management system. Survey questions were drawn from multiple sources, including my own observations with students, and inspired by widely cited studies and reports [5], [23], [38], [39] .

Eligible participants included anyone over the age of 18 who was enrolled at any campus during the Fall 2021 semester. Purposive sampling of the students was performed to ensure that a variety of disciplines and campuses are represented. Enrolled students of any level (undergraduate, graduate, and professional) were asked to participate. Approximately 30% of the students at each campus were included in the initial sample of 29,966 students. The 2,146 responses that were received resulted in a response rate of 8.0%. Of these responses, 2,061 included information about the computing devices the students owned or regularly used. To further narrow the focus of this study, only the responses from students enrolled in a STEM program were examined. All of the programs offered at the study site are assigned to a Classification of Instructional Program (CIP) code, as defined by the National Center for Education Statistics [40]. A subset of CIP codes are classified as "STEM" by the Department of Homeland Security (DHS) Optional Practical Training (OPT) program [41]. Therefore, only students whose primary plan of study is in a program that meets the DHS OPT definition of STEM are included in the analysis, providing a set of 501 responses by students enrolled in a STEM discipline. Survey respondents were then invited to one of three interactive focus groups that were held via Zoom. 21 students (of whom 14 were in STEM disciplines) participated in the focus groups.

A. Definitions

Computing devices were divided into three categories for this study. A **computer** refers to a laptop or desktop computer where the owner has agency to install or manipulate the operating system as desired. A **mobile device** refers to a device that runs a mobile operating system, such as iOS, Android, or iPadOS. **Chromebooks** represent a distinct class of computing devices in that they have the physical features of a laptop computer but a simplified operating system [42] and are used by a small but increasing number of students in higher education [43]. Thus, Chromebooks are treated as a separate classification for this study. Finally, a number of devices in use at the study site blend the features of a laptop and a tablet, such as the Microsoft Surface. Because the Surface uses an operating system designed for a computer (rather than a mobile operating system), respondents were asked to treat the Microsoft Surface as a laptop computer for the purposes of this study.

IV. Results

A. Demographics

The demographics of the responses were diverse and roughly aligned with the population of the university. 54.7% of the respondents were 18-21 years old, 19.4% were 22-25, and 17.6% were 26-35. White students were the largest ethnic group (63.7%), followed by international students, (14.6%), Hispanic/Latino (6.4%), Asian (5.4%), and Black (5.0%). Females made up 54.7% of respondents. Students at all points in their plans of study were represented: 24.0% were undergraduates in their first year, 22.4% in their second, 14.6% in their third, 13.2% in their fourth, and 27.3% were graduate or professional students. Over 140 different plans of study were represented; the five most common majors by the respondents include Biology, Computer Science, Human Biology, Neuroscience, and Informatics. 18.4% of respondents reported being a first-generation student, which is an indicator of parental education level. 21.0% of respondents were eligible for US federal Pell Grants, which is an indicator of financial need. Full-time students were 78.6% of responses, and 73.0% of students lived off-campus. Over 91% of students reported having high-speed internet at their place of residence. Finally, students had a wide range of work commitments: 31% of students do not work, 16.4% of students work 1-10 hours per week, 23.9% work 11-20 hours, 12.9% work 21-39 hours, and 15.5% work 40 hours or more.

B. Device Ownership

Students were provided with a list of device types and were asked to indicate which types of devices they "own or use frequently", the results of which are found in Table I.

TABLE I
Device Ownership Usage (n=501)

Device	Own or Use Frequently
Smart Phone	98.8%
Laptop (incl. Microsoft Surface)	93.4%
Tablet	34.3%
Desktop Computer	32.7%
Chromebook	4.6%

The average number of computing devices owned by students was 2.6 with a mode of 3 devices. The average number of laptop and desktop computers was 1.26 with a mode of 1 computer. 68.0% of students own just one computer. 3.0% of students report not owning a laptop or desktop computer at all. The most common combination of owned devices was a smart phone and a laptop; this was the computing environment for 41.9% of students.

TABLE II
COMBINATIONS OF DEVICE OWNERSHIP USAGE (N=501)

Device Combination	Own or Use Frequently
Smart Phone and Laptop	41.9%
Smart Phone, Laptop, and Tablet	20.2%
Smart Phone, Laptop, and Desktop	16.2%
Smart Phone, Laptop, Desktop, and Tablet	11.6%
Smart Phone, Desktop	2.0%
Smart Phone only	1.6%
Smart Phone and Chromebook	1.0%
Laptop only	0.2%

Students were also asked about the external monitors they owned or used frequently (Table III). 72.9% of laptop owners use only the laptop screen and no external monitor. At least one external monitor is used by 27.1% of students who own laptops. Conversely, just 45.1% of desktop computer users use a single monitor; 45.7% use two monitors and the remainder use three or more.

Five students (1.0%) in the survey reported that they use a Chromebook in lieu of a laptop or desktop computer. Of those five, just one uses an external monitor in addition to the Chromebook screen. Ten students (2.0%) reported owning no computer or Chromebook at all.

TABLE III
NUMBER OF MONITORS USED (N=501)

Computer	Number of monitors/screens		
	1	2	3+
Laptop (n=468)	341 (72.9%)	109 (23.3%)	18 (3.8%)
Desktop (n=162)	74 (45.1%)	75 (45.7%)	13 (7.9%)

C. Demographic Factors of Device Ownership

Logistic regression analysis [44] was used to find the predictors of demographic categories impacting the ownership of computing devices and working environments. The odds ratio was calculated for each explanatory variable for devices owned or frequently used and includes an analysis of computing environments where the student uses just a single screen (either a laptop screen or single external monitor). The results of this analysis are displayed in Table IV.

D. Thematic Analysis of Focus Groups

Three primary themes related to device ownership and use emerged from the focus groups with students. Those themes can be summarized as:

1) Cost
2) Multitasking
3) Personal vs. Academic Use

Related to cost, students generally seemed to accept that they were responsible for acquiring the devices they need to perform academic work. However, although they appeared content with the initial acquisition of the technology, there were several instances where students appeared frustrated with support for physical devices (as opposed to software availability or connectivity). Many students also noted that they purchased the lowest-cost computing option and treated additional devices beyond a computer (such as tablets or external monitors) as optional. Regarding multitasking, students noted that they were often expected to conduct several computing tasks simultaneously. They reported instances where they were unable to successfully complete academic work because they had to repeatedly change between applications (such as an e-textbook and a document in which they were taking notes), or did not have enough room on their screen to conduct multiple tasks simultaneously. Finally, when discussing the expectations of using their devices for academic work, students reported that they felt their laptop or desktop computer was where they conducted their school-related tasks, but noted that they felt their mobile devices were more personal to them and lamented the need to use their mobile devices —- particularly their phones — for academic tasks.

V. DISCUSSION

The survey results show that 97% of students own or have access to a computer (laptop or desktop) and 98.8% own a smart phone. Thus, on the surface, it seems that most students have sufficient devices in which to engage with their studies. A deeper look into that device ownership shows variation between demographic groups and the devices they use. Desktop computer owners are overwhelmingly male – female students are only 25% as likely as male counterparts to own a desktop computer. Desktop computer owners also skew older and are frequently part-time students who live and work off-campus.

Conversely, laptops are pervasive and are more popular with younger students. However, African American and Latino students are significantly less likely to own laptops than their white peers. This corresponds with relatively high Chromebook use by students in those ethnicities: African American and Latino students are over two and a half times more likely to use a Chromebook than other students. Students who are eligible for Pell Grants are also 2.4 times more likely to have a Chromebook than non-Pell eligible students. Price is likely a factor in this situation. In focus groups students who use Chromebooks reported that they were a much cheaper option and offered a similar experience as a laptop. Additionally, younger students noted that they had Chromebooks that were procured while they were finishing their K-12 education in an online/hybrid fashion during the 2020-21 academic year.

The issue of increased use of Chromebooks should be of particular interest to instructors and instructional designers developing curriculum in higher education. The limited operating system of the Chromebook means that students may not be able to install software required by a course. MATLAB, for example, cannot easily be installed directly on a Chromebook [45], [46]. Students without access to a laptop or desktop computer would need to use that application's online portal or the IHE may need to provide access via some kind of virtualized environment. Similarly, students working

TABLE IV
DEMOGRAPHIC FACTORS OF DEVICE OWNERSHIP (ODDS RATIOS)

Demographic	Desktop	Laptop	Tablet	Chromebook	Laptop Only - No Monitor	Desktop – One Monitor
Gender (ref. M)						
F	0.25***	1.10	1.37**	1.30	1.75***	0.77
Age (ref. 18-21)						
22-25	1.82**	1.47	1.27	3.12**	0.75	0.98
26-35	1.95**	1.34	2.09***	6.96	0.41***	1.07
36-45	7.94***	0.77	2.24***	1.47	0.40***	3.05
46-55	3.6**	0.65	2.42***	9.88	0.20***	2.10
56+	3.09	0.44	2.23*	4.10	0.11**	14.09***
Ethnicity (ref. White)						
Asian	1.24	0.52	0.91	0.75	0.94	0.00
African American	0.57	0.41**	0.81	2.57**	1.10	3.91
Hispanic/Latino	0.70	0.28***	0.93	2.72***	0.77	7.30**
Two or More	0.48	0.72	0.93	1.02	1.31	2.92
Unknown	8.99*	0.50	1.06	1.08	0.18	27.11***
Enrollment Type (ref. FT)						
PT	2.05***	0.70**	1.55***	1.09	0.45***	4.70**
International Student						
Yes	0.48**	0.78	1.19	0.40	0.75	0.72
First Generation						
No	1.41	0.60**	0.93	1.45	1.12	1.47
Pell Eligible						
Yes	1.03	0.70	0.74**	2.41***	1.30**	0.78
Student Class. (ref. Undergrad)						
Graduate	1.21					
Living Status						
Off-Campus	2.33***	1.01	1.22	0.82	0.69**	1.13
Hours Worked/wk (ref. 0)						
1-10	1.27	1.10	1.27	0.67	1.08	1.26
11-20	1.72	1.23	0.89	0.67	1.02	1.42
21-39	2.66**	1.05	1.21	1.01	0.93	0.49
40+	3.88***	1.01	1.97***	0.89	0.38***	1.85
Private Study Space						
No	0.56	1.12	0.84	1.11	1.61***	0.92

** $p < .05$; ** $p < .01$; *** $p < .001$*

on a Chromebook would be relegated to the online version of Microsoft Office products as they cannot install the native applications. Situations such as this will require IHEs to invest in licenses that afford online access, and instructors and instructional designers may have to provide additional or alternative instruction for the use of online or alternative interfaces in addition to that of the standard installed software.

The students in the focus groups described intermittent technical issues (primarily with their laptop computers) and reiterated their dependence on having a computer available to them. They noted that the study site supplied most of the software they required as well as connectivity when on campus, but questioned why they had no ability to borrow a device when one was needed. One graduate student described how he fell behind when his laptop was in for repair and he was unable to come to campus to use the facilities. Another student in health sciences described how her laptop had insufficient disk space for two of the applications she was required to use during the semester and that she found herself uninstalling and reinstalling the applications when the need arose.

Insufficient or underpowered devices are reported by students in many studies, but an EDUCAUSE study of students during the COVID-19 pandemic [21] provided a number of practical examples, including:

> "I am sad. My last course required three apps at once... with only 8GB of RAM on my Microsoft laptop, it was not possible to see the teacher and follow each and every step he required... I dropped the course and lost money after 3–4 weeks...this course required Photoshop, Zoom, and a photo editor app running simultaneously."

Tablets are owned by approximately one third (34.3%) of students and are more likely to be owned by females, part-time students, and older students. 80.1% of the tablets owned by students in this study were iPads. This is consistent with other studies that showed tablet ownership is influenced by gender and age (which is correlated with income) [2]. When the focus groups were asked about tablets, the students were divided. Those that owned them noted that they were useful for reading and note-taking and generally supported their academic work. However, students without tablets considered them to be of less importance than a smart phone and a laptop. One focus group participant simply stated that a tablet "...is a lot of money to spend just to see if I like it." Still, they were curious about the additional capabilities of the device, as in one statement: "I don't like to type my notes and I am only able to write with pen and paper... If I had an iPad, I would probably use that." It appears that tablets are treated as an ancillary device, the ownership of which is influenced by their

cost. Students who are eligible for Pell grants are 26% less likely to own a tablet than other students. This study cannot determine if ownership or use of a tablet device impacts the students' academic outcomes, but qualitative evidence from the focus groups appears to be split between students who believe it would help them and those who do not believe so.

The students who own tablets are very likely to use them for academic work. In an analysis of students who own tablets in an introductory chemistry course at the same study site, 93.5% noted that they "would use" or "might use" their tablets to read their course textbook, compared with just 58.6% of students who stated that they would or might use their smart phone for reading a text. Student preferences such as these are important for instructors and instructional designers to consider when selecting and implementing digital course materials. At a minimum, digital materials should be tested for usability and accessibility on mobile devices, computers, and Chromebooks to ensure maximum availability for all students.

Differences were also found in the number of screens in use by the students. Almost 73% of students who use a laptop use the built-in laptop screen alone, whereas just 45% of desktop computer users limit themselves to a single screen (although the screen sizes for desktop computers are much more variable than laptop screens). This is an important factor to consider now that so much of students' academic work has been digitized and they are more likely than prior to the pandemic to engage with videoconferencing and video-based resources in their coursework. In open-ended survey feedback, students frequently reported the necessity of having multiple digital resources available at the same time. One student noted that she often requires "...access to multitasking (i.e., watching a pre-recorded lecture or video and taking notes on Word at the same time)." This situation can also an impediment for online courses, as reported by one student: "Online classes are frequently taken on a laptop so I cannot view the class and a full laptop screen at the same time." A focus group participant noted a similar experience and reported dropping a course that required him to follow along with computer-based tutorials to learn how to use Photoshop – he simply couldn't perform the activity while watching the tutorial simultaneously.

The demographics for students who use a single laptop screen tend to be younger, female, full-time students who live on campus. These students may have the advantage of using campus-based computing resources (although focus group participants noted they preferred their own computers and would like docking stations rather than using a computer provided in a computer lab). Students who live off-campus or are enrolled in online coursework may not have access to the same campus-based resources and, in the case of online courses that rely on videoconferencing or video, may be at a disadvantage when using a single screen. There are few studies that have examined the influence of multiple screens on student academic performance but at least anecdotally it appears that students may benefit from the ability to work with more than a single screen at a time [36], [37]. At the very least, lack of screen real estate has posed a barrier to some students while performing academic work.

Students reported that some of their multitasking was accomplished by using their mobile device —– most often a smart phone —– to perform some academic tasks. However, students were selective about the tasks that they wished to perform on their devices [35]. They also repeatedly emphasized that they treated their mobile phone as their personal computing device and regarded its use for academic work as one that should be *their* choice. Several students noted, however, that using their phone for academic work was at least occasionally unavoidable and appreciated the convenience when the functionality worked as expected.

VI. Conclusion

This study demonstrates that, while the first-level digital divide of ownership and internet access may appear to be of little issue to students in higher education, the personal computing environments of students are far from uniform. Minority students do not appear to have the same level of computing device ownership as their peers, and there appear to be significant gender-based differences in the devices that are in use. Several barriers were also cited by the respondents. Students have noted that they are expected to multitask with a variety of digital resources in their everyday academic work and this can be challenging with limited computing resources. Students have also demonstrated a willingness and, indeed, desire to interact with digital course materials on a wide range of computing devices. Digital course materials must be tested for compatibility on the devices actually used by students to perform academic work. Instructors must be ready to support students who are using non-traditional computing environments and be able to direct students to resources when specific computing needs arise. As STEM courses are dependent on students' access to digital materials, tools, and software, the demographic differences in device ownership should be taken into consideration during any examination of the diversity, equity, and inclusion (DEI) of student populations in STEM majors.

VII. Areas for Future Study

A plurality of students (41.9%) report a laptop and a smart phone as the extent of their academic computing environment. This cohort of students is overwhelmingly young, female, full-time, Pell-eligible, and lives on campus. Although those that reside on campus have access to computer labs, students repeatedly emphasized that their preference is to work on their personal devices. More study is also needed to discover if the computer labs and services provided by the study site meets the expectations and needs of the students.

Almost three quarters of students who use a laptop (72.9%) report that they do not have an external monitor to use with their computer, and just about one third (34.3%) report ownership or use of a tablet. Comments from the student focus groups indicate that these tools may be useful to students but may also be cost prohibitive and/or are not considered necessities by the students. Further study is needed related

to the impact of peripherals, particularly external monitors and tablets, to determine if students' current computing environments afford them adequate functionality to successfully conduct academic tasks. A study that affords students the opportunity and training to use tablets at no initial cost would provide valuable data in this area.

References

[1] M. Cohron, "The continuing digital divide in the United States," *The Serials Librarian*, vol. 69, no. 1, pp. 77–86, 2015, ISSN: 0361-526X. DOI: 10.1080/0361526x.2015.1036195.

[2] A. J. v. Deursen and J. A. v. Dijk, "The first-level digital divide shifts from inequalities in physical access to inequalities in material access," *New Media & Society*, vol. 21, no. 2, pp. 354–375, 2019, ISSN: 1461-4448. DOI: 10.1177/1461444818797082.

[3] A. Gonzales, "The contemporary US digital divide: from initial access to technology maintenance," *Information, Communication & Society*, vol. 19, no. 2, pp. 234–248, 2015, ISSN: 1369-118X. DOI: 10.1080/1369118x.2015.1050438.

[4] E. Hargittai, "Second-level digital divide: Differences in people's online skills," *First Monday*, vol. 7, no. 4, Apr. 2002. DOI: 10.5210/fm.v7i4.942. [Online]. Available: https://firstmonday.org/ojs/index.php/fm/article/view/942.

[5] J. D. Galanek, D. C. Gierdowski, and D. C. Brooks, "ECAR study of undergraduate students and information technology (2018)," EDUCAUSE Center for Analysis and Research, Louisville, CO, Tech. Rep., Oct. 2018. [Online]. Available: https://tacc.org/sites/default/files/documents/2018-11/studentitstudy2018%5C_0.pdf.

[6] M. Banerjee, "An exploratory study of online equity: Differential levels of technological access and technological efficacy among underserved and underrepresented student populations in higher education," *Interdisciplinary Journal of E-Skills and Lifelong Learning*, vol. 16, pp. 93–121, Feb. 2020. DOI: 10.28945/4664.

[7] V. S. Katz, A. B. Jordan, and K. Ognyanova, "Digital inequality, faculty communication, and remote learning experiences during the COVID-19 pandemic: A survey of U.S. undergraduates," *PLoS ONE*, vol. 16, no. 2, e0246641, 2021. DOI: 10.1371/journal.pone.0246641.

[8] B. C. Reisdorf, W. Triwibowo, and A. Yankelevich, "Laptop or bust: How lack of technology affects student achievement," *American Behavioral Scientist*, vol. 64, no. 7, pp. 927–949, 2020, ISSN: 0002-7642. DOI: 10.1177/0002764220919145.

[9] B. Dogan and B. Robin, "Technology's role in STEM education and the STEM SOS model," in *A practice-based model of STEM teaching: STEM students on the stage (SOS)*, A. Sahin, Ed., Sense Publishers, Feb. 2015, pp. 77–94, ISBN: 978-9463000178.

[10] J. Ryoo and K. Winkelmann, Eds., *Innovative learning environments in STEM higher education: Opportunities, challenges, and looking forward*. Switzerland: SpringerBriefs in Statistics, Feb. 2021, ISBN: 978-3-030-58947-9. [Online]. Available: https://link.springer.com/book/10.1007/978-3-030-58948-6.

[11] J. Mella-Norambuena, R. Cobo-Rendon, K. Lobos, F. Sáez-Delgado, and A. Maldonado-Trapp, "Smartphone use among undergraduate STEM students during COVID-19: An opportunity for higher education?" *Education Sciences*, vol. 11, no. 8, p. 417, 2021. DOI: 10.3390/educsci11080417.

[12] D. C. Gierdowski, "ECAR study of community college students and information technology, 2019," ECAR, Louisville, CO, Tech. Rep., May 2019. [Online]. Available: https://www.educause.edu/ecar/research-publications/ecar-study-of-community-college-students-and-information-technology/2019/introduction-and-key-findings.

[13] M. Honey, B. Alberts, H. Bass, *et al.*, "STEM education for the future: A visioning report," Tech. Rep., Feb. 2020, p. 36. [Online]. Available: https://www.nsf.gov/ehr/Materials/STEM%5C%20Education%5C%20for%5C%20the%5C%20Future%5C%20-%5C%202020%5C%20Visioning%5C%20Report.pdf.

[14] R. Kimmons, "Current trends (and missing links) in educational technology research and practice," *TechTrends*, vol. 64, no. 6, pp. 803–809, 2020, ISSN: 8756-3894. DOI: 10.1007/s11528-020-00549-6.

[15] A. Demb, D. Erickson, and S. Hawkins-Wilding, "The laptop alternative: Student reactions and strategic implications," *Computers & Education*, vol. 43, no. 4, pp. 383–401, 2004, ISSN: 0360-1315. DOI: 10.1016/j.compedu.2003.08.008.

[16] J. M. R. Asio, E. D. Gadia, E. C. Abarintos, D. P. Paguio, and M. Balce, "Internet connection and learning device availability of college students: Basis for institutionalizing flexible learning in the new normal," *Studies in Humanities and Education*, vol. 2, no. 1, pp. 56–69, Jun. 2021. DOI: 10.48185/she.v2i1.224. [Online]. Available: https://sabapub.com/index.php/she/article/view/224.

[17] *EDUCAUSE Homepage*. [Online]. Available: https://www.educause.edu/ (accessed 04/15/2022).

[18] *EDUCAUSE Student & Faculty Technology Studies*. [Online]. Available: https://library.educause.edu/resources/2021/10/educause-student-and-faculty-technology-studies (accessed 04/15/2022).

[19] K. N. Hampton, L. Fernandez, C. T. Robertson, and J. M. Bauer, "Broadband and student performance gaps," Tech. Rep., Mar. 2020. [Online]. Available: https://quello.msu.edu/wp-content/uploads/2020/03/Broadband%5C_Gap%5C_Quello%5C_Report%5C_MSU.pdf.

[20] C. Hodges, S. Moore, B. Lockee, T. Trust, and A. Bond, *The difference between emergency remote teaching and*

online learning, Mar. 2020. [Online]. Available: https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning (accessed 04/14/2022).

[21] D. C. Gierdowski, "Student Experiences with Connectivity and Technology in the Pandemic," EDUCAUSE, Boulder, CO, Tech. Rep., Apr. 2021.

[22] A. Kukulska-Hulme and J. Traxler, "Rethinking pedagogy for a digital age," in *Rethinking Pedagogy for a Digital Age: Principles and Practices of Design*, H. Beetham and R. Sharpe, Eds., New York, NY: Routledge, Jul. 2019, ISBN: 9781351252805. DOI: 10.4324/9781351252805. [Online]. Available: https://doi.org/10.4324/9781351252805.

[23] S. Cross, M. Sharples, G. Healing, and J. Ellis, "Distance learners' use of handheld technologies: Mobile learning activity, changing study habits, and the 'place' of anywhere learning," *The International Review of Research in Open and Distributed Learning*, vol. 20, no. 2, Apr. 2019. DOI: 10.19173/irrodl.v20i2.4040. [Online]. Available: http://www.irrodl.org/index.php/irrodl/article/view/4040.

[24] V. Mathew, A. I. Abduroof, and J. Gopu, "Transforming higher education through digitalization," in *Transforming Higher Education Through Digitalization : Insights, Tools, and Techniques*, S. L. Gupta, N. Kishor, N. Mishra, S. Mathur, and U. Gupta, Eds., Boca Raton, FL: CRC Press, Oct. 2021, pp. 145–171, ISBN: 9781000461299. DOI: 10.1201/9781003132097-9.

[25] J. Bezemer and G. Kress, "Writing in multimodal texts: A social semiotic account of designs for learning," *Written Communication*, vol. 25, no. 2, pp. 166–195, Apr. 2008, ISSN: 0741-0883. DOI: 10.1177/0741088307313177. [Online]. Available: https://doi.org/10.1177/0741088307313177.

[26] A. L. Gonzales, J. M. Calarco, and T. Lynch, "Technology problems and student achievement gaps: A validation and extension of the technology maintenance construct," *Communication Research*, vol. 47, no. 5, pp. 750–770, 2020, ISSN: 0093-6502. DOI: 10.1177/0093650218796366.

[27] J. Pomerantz, M. Brown, and D. C. Brooks, "Foundations for a next generation digital learning environment: Faculty, students, and the LMS," en, ECAR, Louisville, CO, Tech. Rep., 2018, p. 16. [Online]. Available: https://library.educause.edu/-/media/files/library/2018/1/ers1801.pdf.

[28] D. Wilcox, J. Thall, and O. Griffin, "One Canvas, two audiences: How faculty and students use a newly adopted learning management system," in *Society for Information Technology & Teacher Education International Conference*, Waynesvile, NC: Association for the Advancement of Computing in Education, Mar. 2016, ISBN: 978-1-939797-13-1. (accessed 04/29/2022).

[29] C. B. Mpungose and S. B. Khoza, "Postgraduate students' experiences on the use of Moodle and Canvas learning management system," *Technology, Knowledge and Learning*, pp. 1–16, 2020, ISSN: 2211-1662. DOI: 10.1007/s10758-020-09475-1.

[30] J. Schoonenboom, "Using an adapted, task-level technology acceptance model to explain why instructors in higher education intend to use some learning management system tools more than others," *Computers & Education*, vol. 71, pp. 247–256, 2014, ISSN: 0360-1315. DOI: 10.1016/j.compedu.2013.09.016.

[31] D. Laurillard, "The pedagogical challenges to collaborative technologies," *International Journal of Computer-Supported Collaborative Learning*, vol. 4, no. 1, pp. 5–20, 2009, ISSN: 1556-1607. DOI: 10.1007/s11412-008-9056-2.

[32] R. Seilhamer, B. Chen, S. Bauer, A. Salter, and L. Bennett, *Changing mobile learning practices: A multiyear study 2012–2016*, en, 2018. [Online]. Available: https://er.educause.edu/articles/2018/4/changing-mobile-learning-practices-a-multiyear-study-2012-2016 (accessed 11/03/2020).

[33] L. Robinson, "Endowed, Entrepreneurial, and Empowered-Strivers: Doing a lot with a lot, doing a lot with a little," *Information, Communication & Society*, vol. 17, no. 5, pp. 521–536, Mar. 2014, ISSN: 1369-118X. DOI: 10.1080/1369118x.2013.770049.

[34] C. Kang, "Bridging a digital divide that leaves schoolchildren behind," *New York Times*, Feb. 2016. [Online]. Available: https://www.nytimes.com/2016/02/23/technology/fcc-internet-access-school.html?%5C_r=0.

[35] R. Elliott, "The use of mobile devices for formal learning in higher education: Investigating student behaviors and expectations," English, Bloomington, IN, Feb. 2022. [Online]. Available: https://hdl.handle.net/2022/27468.

[36] J. Lanir, K. S. Booth, and K. Hawkey, "The benefits of more electronic screen space on students' retention of material in classroom lectures," *Computers & Education*, vol. 55, no. 2, pp. 892–903, 2010, ISSN: 0360-1315. DOI: 10.1016/j.compedu.2010.03.020.

[37] J.-M. Hsu, T.-W. Chang, and P.-T. Yu, "Learning effectiveness and cognitive loads in instructional materials of programming language on single and dual screens," *Turkish Online Journal of Educational Technology*, vol. 11, no. 2, pp. 156–166, Apr. 2012, ISSN: 1303-6521.

[38] D. C. Gierdowski, D. C. Brooks, and J. Galanek, "2020 Student technology report: Supporting the whole student," EDUCAUSE Center for Analysis and Research, Louisville, CO, Tech. Rep., Oct. 2020. [Online]. Available: https://library.educause.edu/resources/2020/10/2020-student-technology-report-supporting-the-whole-student.

[39] J. Gikas and M. M. Grant, "Mobile computing devices in higher education: Student perspectives on learning with cellphones, smartphones & social media.," *Internet & Higher Education*, vol. 19, pp. 18–26, Oct. 2013.

DOI: 10.1016/j.iheduc.2013.06.002. [Online]. Available: https://www.ulib.iupui.edu/cgi-bin/proxy.pl?url=https://search.ebscohost.com/login.aspx?direct=true%5C&db=lxh%5C&AN=90637482%5C&site=eds-live.

[40] *Classification of Instructional Programs (CIP)*. [Online]. Available: https://nces.ed.gov/ipeds/cipcode/default.aspx?y=56 (accessed 04/02/2022).

[41] *Eligible CIP Codes for the STEM OPT Extension*. [Online]. Available: https://studyinthestates.dhs.gov/stem-opt-hub/additional-resources/eligible-cip-codes-for-the-stem-opt-extension (accessed 04/02/2022).

[42] R. Pegoraro, "What Is a Chromebook?" *U.S. News & World Report*, Mar. 2021. [Online]. Available: https://www.usnews.com/360-reviews/technology/laptops/what-is-a-chromebook (accessed 03/03/2022).

[43] M. Banerjee, "An exploratory study of online equity: Differential levels of technological access and technological efficacy among underserved and underrepresented student populations in higher education," *Interdisciplinary Journal of E-Skills and Lifelong Learning*, vol. 16, pp. 93–121, Feb. 2020. DOI: 10.28945/4664.

[44] S. Sperandei, "Understanding logistic regression analysis," *Biochemia Medica*, vol. 24, no. 1, pp. 12–18, 2014, ISSN: 1330-0962. DOI: 10.11613/bm.2014.003.

[45] *How could I run MatLab on a Chromebook?* Aug. 2013. [Online]. Available: https://www.mathworks.com/matlabcentral/answers/84055-how-could-i-run-matlab-on-a-chromebook (accessed 07/19/2022).

[46] *Matlab on an Acer Chromebook?* Jan. 2018. [Online]. Available: https://www.mathworks.com/matlabcentral/answers/378123-matlab-on-an-acer-chromebook (accessed 07/19/2022).