The Demographics of Student Device Ownership: An Examination of the Personal Computing Ecosystems of Students in Higher Education

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ABSTRACT: Higher education has become dependent on the use of digital materials, which may include texts, audiovisual content, and software applications. Because students in higher education are largely responsible for providing the computing devices they are required to use to interact with their digital course materials, instructors and instructional designers are often unaware of the personal computing ecosystems in use by their students. This study describes a large-scale survey of student ownership and use of computing devices at a large public university in the midwestern United States. The results demonstrate that students generally have access to devices that allow them to engage with their digital course materials, but age and demographic factors correlated with socioeconomic status appear to impact the type and quality of devices owned. The study also shows that students have access to a variety of device types and that most students perform their computing tasks on a single screen. Understanding the personal computing ecosystems of students will allow instructors and instructional designers to develop course materials that are accessible to students on the devices in use and can inform the decision-making process when an institution considers adoption of new learning technologies. This data can also be used as a foundation for future studies that examine the influence of a student's technology access and ownership on their academic outcomes.

Keywords: Computer-supported collaborative learning, Distance learning/education, Mobile computing, Technology enhanced language learning

1. Introduction

Higher education has become inextricably intertwined with technology (Becker et al., 2017; Gierdowski, 2019b) and students are increasingly bringing more personal technology with them to school (Gierdowski et al., 2020). Cosentino (2020) notes that "…we come to knowledge by engaging with digital technologies that are embedded and embodied, and that extend our cognition" (p. 14). In most cases in higher education in the United States, the students themselves are responsible for supplying the computing devices needed to take advantage of the digital technologies in use in higher education today. The use of computing devices allows students to perform academic work unbounded by classrooms and at the time and place of their choosing (Kukulska-Hulme & Traxler, 2019). Therefore, it is imperative that educators understand the contexts in which students experience their course materials, which are referred to here as the students' "computing ecosystem." If the computing devices through which the digital content is delivered cannot support the activities in which the students must engage, then the benefits of the technology-enhanced learning are diminished or lost (Taylor et al., 2006).

The transition of physical classroom interactions and media into their digital equivalents is both intrinsic, as students see the value of using technology to support their studies (Gierdowski, 2019b), as well as extrinsic, as most institutions have adopted learning management systems (LMS) for communication and organization of instructional materials (Pomerantz et al., 2018). Pomerantz et al. (2018) note that 99% of institutes of higher education (IHEs) have adopted LMS platforms for communication and organization of instructional materials. Further, 88% of faculty were found to use at least some features of the LMS, which indicates they expect students to engage with their courses via some form of computing device. Even prior to the COVID-19 pandemic, most students reported that an LMS was used for "…most or all of their courses" (Galanek et al., 2018, p. 5). IHEs have become replete with technology for even the most mundane classroom tasks (Becker et al., 2017; Gierdowski, 2019b).

Because of this reliance on digital activities in support of academic coursework, a computing device that allows a student to engage with the LMS and other internet and communication technologies (ICTs) used for instruction at an IHE is a de facto, if not outright, requirement (Reisdorf et al., 2020). Indeed, students express a preference for digital learning materials and increased faculty use of technology (Gierdowski, 2019b). Therefore, it is imperative for IHEs and instructors to understand the personal technology owned and used by students – their personal computing ecosystems. Selwyn (2010) argues that "…greater attention now needs to be paid to how digital technologies are actually being used – for better and worse – in 'real-world' educational settings" (p. 66).

To understand this, Allen (2016) notes that faculty and institutions must become familiar with the technology that students use for their academic work. Although the need to understand the technology in use by students has long existed, the transition to online learning due to the COVID-19 pandemic exposed several gaps related to the personal technology in use by students (Gierdowski, 2021; Jaggars et al., 2021).

The so-called "digital divide" is incorrectly thought of as a binary distinction between those who have technology and those who do not (OECD, 2006). More in-depth research into the digital divide generally considers three strata of divisions (Ferreira et al., 2021). The first is access to computing devices and the connectivity required to use them (Deursen & Dijk, 2019; OECD, 2006). The second-level divide examines the computer and information literacy needed to make use of one's computing ecosystem (Dijk, 2006; Hargittai, 2002). Finally, there is a tertiary level that researches an individual's ability to use the computing devices and connectivity to achieve specific outcomes (Cohron, 2015; Rowsell et al., 2017). Obviously, one cannot bridge either the second or third level of the digital divide without the devices and internet access afforded in the first level and IHEs in the United States generally operate on the assumption that their students have sufficient computing access and connectivity to complete their academic requirements (Brooks et al., 2020). However, the quality of the devices in use by individuals can vary wildly (Deursen & Dijk, 2019) and students frequently report difficulties related to connectivity when trying to conduct academic work (Galanek et al., 2018; Gierdowski, 2021; Means & Neisler, 2020). Because of the disparities in student experience related to personal technology, it is important to have a broader understanding of student access to computing devices and connectivity as well as their positive and negative experiences in their everyday use.

This study describes the results of a comprehensive survey of students at a large, multi-campus, public institution of higher education in the midwestern United States which sought to quantify the personal technology those students own and use to complete their collegiate academic work. The purpose of this study is to answer two broad research questions:

- What is the computing ecosystem in use by students at a large public institution of higher education in the United States?
- How do the computing ecosystems of students differ between demographic subgroups?

The results of this study are intended to inform instructors and instructional designers about the personal computing devices in use by their students and provide insight to the potential discrepancies between different subgroups of students with whom they engage. This study should also be useful to the decision-makers at IHEs who are responsible for the evaluation and selection of learning technologies on an institutional scale so that they are able to evaluate the technologies in the context of what students are able to use.

2. Literature review

Students are required to engage with a menagerie of course materials in multiple digital formats and modalities. Traditional textbooks are being replaced or supplemented by electronic texts, interactive digital content, and open educational resources (OER), which is distributed digitally (Moro, 2018; Seaman & Seaman, 2019). Courses have grown beyond the physical confines of the classroom and often include audiovisual content either produced or recommended by the instructor (Brame, 2016). Hybrid and online learning opportunities, which were already on the rise prior to the COVID-19 pandemic, have significantly increased since 2020 and have resulted in additional digital resources for students, including live online interactions and recordings of lectures and classroom sessions (MacKay, 2019). Beyond merely accessing course materials, students are also required to use computers for summative coursework, including proctored exams, digital presentations, and research papers (Schoonenboom, 2012). Students are also occasionally expected to make use of platforms with no physical equivalent, such as social media (Farkas, 2012).

The incorporation of digital artifacts and activities with traditional classroom interaction has been labeled "blended learning" (Owston, 2018), but instructors predominantly use the technology for administrative purposes to improve their efficiency and primarily for the top-down dissemination of academic materials to students (Mpungose & Khoza, 2020; Torrisi-Steele & Drew, 2013). However, because the of transition of physical classroom artifacts into their digital equivalents is so commonplace, Pomerantz et al. (2018) argue that "…it may be time to stop considering trivial uses of online tools (such as using an LMS to post a course syllabus) as worthy of qualifying a course as 'blended' " (p. 4). Laurillard (2005) uses the term "e-learning" to describe the "…shar(ing) of resources across networks," which allows for "…greater flexibility of provision in time and place" (p. 72).

Although it has been demonstrated that students are increasingly bringing more personal technology with them for use in higher education (Gierdowski et al., 2020), detailed information about that technology can be difficult to find. Studies regarding the academic impact of a specific technology will often include details about the particular device(s) of focus but rarely offer a broad picture of student device ownership (Chen et al., 2002; Kenny et al., 2009; Margaryan et al., 2011). EDUCAUSE, a higher education technology advocacy group, conducts a longitudinal study to learn more about the interaction of students in higher education and technology (Galanek et al., 2018; Gierdowski, 2019b; Gierdowski et al., 2020). However, the EDUCAUSE reports, while valuable, do not provide a specific breakdown of the ownership of computing devices. The annual National Survey of Student Engagement (Indiana University Bloomington School of Education, n.d.) included an optional "Learning with Technology" module that was discontinued in 2020. The University of Central Florida (UCF) Center for Distributed Learning conducts a semi-annual survey of student mobile device ownership that reveals near-universal ownership of smart phones but varying levels of tablet ownership and does not include information about the computers used by the students (UCF Center for Distributed Learning, 2018). The Pew Research Center regularly produces reports on computing device ownership of the US population as a whole (Anderson, 2015), but rarely focuses on college students (Smith et al., 2011). Therefore, it is often difficult for researchers to find comprehensive statistics about the computing devices in use by students in higher education. The purpose of this study is to provide a foundational overview of device ownership to assist in the development of additional research questions and allow researchers to delve further into the relationship between a student's personal technology and their success at meeting learning outcomes.

It can be argued that information about student device ownership is critical in the context of understanding student engagement with their digital course materials and their overall academic performance. For example, a 2020 study notes that approximately 20% of students struggle with the technology they have at their disposal and that those with lower-quality computers have lower GPAs (Gonzales et al., 2020). Jaggars et al. (2021) found that 8% of students reported hardware or software issues that were serious enough to disrupt their academic work during the transition to online learning due to COVID-19. These findings support the notion that populations with lower socioeconomic status (SES) have higher barriers to reliable technology and connectivity (Banerjee, 2020; Bell et al., 2022; Gonzales, 2014; Mark et al., 2017) and those technical difficulties are harder to overcome for students of lower SES (Bernhaupt et al., 2020). However, SES disparities are not the only explanation for differences in student performance. Research has shown that students with inadequate computing resources demonstrate worse academic performance than their peers even when controlling for SES factors (Reisdorf et al., 2020). Siani (2017) notes that pedagogy based on the assumption of students' personal technology ownership must consider the digital divide between students who possess and can competently use devices (the first and second level digital divides) and those who cannot.

The access to and quality of a student's computing devices has been shown to have a cascade effect on their academic engagement and performance. Students' ability to cope with technical difficulties (Pituch & Lee, 2006) and access to technical support (Sánchez et al., 2013) can improve their computing self-efficacy. Improved self-efficacy, in turn, contributes to a students' perceived usefulness of a learning technology (Huang, 2020). Alsabawy et al. (2016) found that the quality of the IT infrastructure of an e-learning system – which, we must assume, includes the devices on which the student is engaging – also has a direct effect on the student's perceived usefulness of that system. Perceived usefulness, defined by Davis (1989) as "…the degree to which a person believes that using a particular system would enhance his or her job performance" (p. 320) has frequently been used to gauge students' willingness to use personal technology for academic work in higher education (Alsabawy et al., 2016; Lai et al., 2012). Measuring usefulness related to information technology has been expanded into the Technology Acceptance Model (TAM) (Davis et al., 1989), which has similarly been used to examine the factors that determine a students' adoption of technology to engage in their academic work. A meta-analysis of this work was performed by Granić and Marangunić (2019).

Consequently, students with limited or inadequate access to computing devices can demonstrate lower levels of computer and digital literacy than their peers (Hargittai, 2002; Hargittai, 2010). A students' lack of digital literacy can negatively affect their usage of e-learning technologies, such as an LMS (Oz et al., 2015). The task-technology-fit (TTF) model posits that there is a connection between a user's experience with a technology and its subsequent utilization (Goodhue & Thompson, 1995). McGill and Klobas (2009) applied the TTF model to LMS usage and found that students' perception of a fit between the task and the technology used to accomplish the task had a significant effect on their attitude toward LMS use. If a student's technology cannot accomplish the tasks they are expected to perform, their attitude toward the entire academic endeavor may suffer.

Although laptops and computers are most often the focus of research related to student computing devices, studies show that students are increasingly using handheld mobile devices – such as phones and tablets – to engage with their academic work (Cross et al., 2019; Gierdowski et al., 2020; Magda et al., 2020; Seilhamer et

al., 2018). Therefore, understanding the mobile devices students own and use may be important when making a comprehensive examination of student academic engagement through technology. Other work investigates the impact of allowing students to view multiple digital inputs simultaneously and suggests that students retain information better when they have more viewable screen area or multiple screens (Hsu et al., 2012; Lanir et al., 2010; Lanir et al., 2013; Miller et al., 2020). Given the variety of computing devices and peripherals used in the conduct of academic work, it stands to reason that a broad overview of the hardware in use by students is an important factor in any examination of a student's relationship with digitalized course materials. This study provides such an overview as both a model for similar studies as well as a foundation for further research in the use of personal technology in higher education.

3. Methods

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 nine physical campuses (including a core residential campus, a large urban semi-residential campus, five regional campuses, and two satellite campuses) and a slate of exclusively online programs. All students in an online program are also assigned to one of the nine physical campuses and thus appear in the results for that campus type. Eligible participants included anyone over the age of 18 who was enrolled at any campus during the Fall 2021 semester. Enrolled students of any level (undergraduate, graduate, and professional) were asked to participate.

Purposive sampling of the students was performed to ensure that a variety of disciplines and campuses are represented. Approximately 30% of the students at every campus were included in the initial sample. 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 previous ad hoc interactions with students, and inspired by widely cited studies and reports (Cross et al., 2019; Galanek et al., 2018; Gierdowski et al., 2020; Gikas & Grant, 2013). In addition to asking about the computing devices owned, students were also asked to report the number of external monitors used with their computers, thus allowing the separate calculation of the number of device screens and the total number of computing screens. The survey also asked students about demographic factors that are not part of the institutional demographic profile, such as number of hours worked per week, living situation, and availability of high-speed internet.

The survey responses were then paired with institutional demographic records about each respondent (including their major, age, and enrollment status). The survey results were analyzed with both descriptive and inferential statistics (Leedy & Ormrod, 2016) using Python 3.8 and the statsmodels package. Crosstabulations and multiple regression analyses (Flick, 2015) were performed to reveal relationships between demographic and ownership factors (i.e., do students from regional campuses own desktop computers at a higher rate than students at the larger campuses?)

3.1. Definitions in this study

For the purposes of this study, computing devices are divided into three distinct categories. The term "mobile device" is defined as one that uses a mobile operating system (such as iOS, Android, or iPadOS). This includes smart phones and tablets such as iPads. "Computers," therefore, are defined as devices that run a full version of an operating system (including laptops and hybrid tablet/laptops such as the Microsoft Surface). Chromebooks represent a hybrid device in that they use ChromeOS – a limited, semi-mobile operating system – but have the physical affordances of a traditional laptop computer (Pegoraro, 2021). Thus, "Chromebooks" are treated as a third class of device in this study.

4. Results

All students over the age of 18 who were enrolled in the Fall 2021 semester at any campus or online program of the university was eligible to participate in the anonymous student survey. A sample of 26,966 eligible students was created. From this sample, 149 individuals were removed because of invalid email addresses. This sample represented approximately 30% of all eligible participants at the university. The survey began on October 11, 2021 and remained open for 28 days until November 8, 2021. Survey invitations were delivered via Qualtrics' internal email distribution system. All participants received an initial invitation to participate followed by two reminder messages sent at weekly intervals. The 2,146 responses that were received resulted in a response rate of

8.0%. Of these responses, 2,041 included information about the computing devices the students owned or regularly used.

4.1. Demographic overview of responses

The demographics of the respondents were diverse and roughly aligned with the population of the university. 55.9% of the respondents were 18-21 years old, 16.2% were 22-25, and 14.9% were 26-35. White students were the largest ethnic group (68.0%), followed by Hispanic/Latino (8.0%), Black/African American (5.9%), and Asian (5.3%). Females were somewhat overrepresented and made up 65.0% of respondents. International students provided 7.9% of the responses. Students at all points in their plans of study were represented: 22.5% were undergraduates in their first year, 15.6% in their second, 14.0% in their third, and 20.2% were in their fourth. Graduate and professional students account for the remaining 27.7% of responses. Over 140 different plans of study were included in the sample; the five most common majors by the respondents include Finance, Psychology, Biology, Computer Science, and Nursing. 46.5% of the responses were from the core campus, 29.2% from the urban campus, 22.0% from the regional campuses, and 2.3% were from the satellite campuses. 22.1% of respondents reported being a first-generation student, which is an indicator of parental education level. 21.5% of respondents were eligible for US federal Pell Grants, which is an indicator of financial need. Full-time students were 80.4% of responses, and 78.1% of students lived off-campus. Students with a private, unshared study space made up 78.6% of responses. Over 91% of students reported having high-speed internet at their place of residence. Finally, students had a wide range of work commitments: 31.6% of students do not work, 12.6% of students work 1-10 hours per week, 22.4% work 11-20 hours, 16.2% work 21-39 hours, and 17.2% work 40 hours or more.

4.2 Summary of device ownership

When inquiring about ownership, the decision was made to use more inclusive language; thus, students were asked to identify each of the computing devices that they "own or regularly use." The results appear in Table 1.

Table 1. Computing device ownership (n = 2041)

Device	# of students who own	Percentage of respondents
Smart phone	2,006	98.3%
Laptop	1,887	92.5%
Tablet	718	35.2%
Desktop computer	513	25.1%
E-reader	125	6.1%
Chromebook	115	5.6%
"Basic" mobile phone	10	0.5%

E-readers (such as a Kindle) and basic mobile phones provide limited access to the learning technologies in place at the study site. Therefore, the remainder of the analysis will focus on ownership and use of five computing devices: smart phones, tablets, laptop and desktop computers, and Chromebooks.

Table 2 demonstrates that laptops are the most common computer in the study and are owned (or used) by 92.4% of respondents. Although 25.1% of respondents report owning or using a desktop computer, just 2.3% of respondents exclusively use a desktop. Laptops are also the only non-mobile computing device for 68.3% of respondents. Computer and Chromebook ownership is high but not universal – 2.6% of respondents report that they have neither a computer nor a Chromebook.

Table 2. Computer and Chromebook ownership (n = 2041)

Device	% of students who own	% of students w/o another computer
Laptop computer	92.4%	68.3%
Desktop computer	25.1%	2.3%
Chromebook	5.6%	2.2%

A plurality of respondents – 48.8% – own just two of the five computing devices included in the study. The most common combination of computing devices, as depicted in Table 3, is a smart phone and laptop, which is the computing ecosystem used by 44.5% of respondents in the study. While few students (2.2%) appear to be dependent on a Chromebook in lieu of a laptop or desktop computer a gender disparity exists. 2.3% of

respondents who identify as female use a smart phone and Chromebook combination, compared to just 0.8% of respondents who identify as male.

Table 3. Common device ownership combinations (n = 2041)

Device	# of students	% of sample
Smart phone, laptop	908	44.5%
Smart phone, laptop, tablet	465	22.8%
Smart phone, desktop, laptop	245	12.0%
Smart phone, desktop, laptop, tablet	188	9.2%
Smart phone, Chromebook	36	1.8%
Smart phone	31	1.5%

Table 4 shows that the majority of respondents report use a single screen when using a computer or Chromebook, regardless of the type of device in use. For laptops and Chromebooks that single screen is the screen attached to the device itself. Although most respondents who use desktop computers do use a single screen, respondents with desktops are more likely to have two screens than those using a laptop or a Chromebook. These numbers may also be influenced by the wide range of possible desktop monitor sizes, which were not included in the survey; a single external monitor could effectively have the same physical dimensions of two or more smaller screens.

Table 4. Number of computer and Chromebook screens (n = 2041)

Device	# (%) of students who own	% of owners using		
		1 screen	2 screens	3+ screens
Laptop computer	1887 (92.4%)	76.3%	20.1%	3.4%
Laptop computer only	1393 (68.3%)	79.6%	18.1%	2.3%
Desktop computer	513 (25.1%)	56.5%	38.4%	5.1%
Chromebook	115 (5.6%)	79.0%	18.4%	2.6%
Chromebook only	44 (2.2%)	86.4%	13.6%	0.0%

4.3. Influence of demographics on device ownership

Logistic regression analysis was used to discover predictors of demographic categories that may have an impact on the ownership and computing devices and working environments in use by respondents. The odds ratio was calculated for each explanatory demographic variable for three of the most owned or used computing devices (desktop computer, laptop computer, and tablet). Further, odds ratios were also calculated for three computing ecosystems where a student uses a single screen for their academic work. The result of this analysis is found in Table 5.

A student's age was found to be a significant predictor in both desktop computer and tablet ownership, as well as the use of a laptop with no monitor or a desktop computer with a single monitor. Because age was such a statistically significant predictor for these variables, logistic regression analysis was conducted a second time while controlling for the age of the respondent. The results of the secondary analysis generally confirmed the first but revealed additional statistically significant interactions between demographics and device ownership and use. When controlling for age, international students were found to be less likely to own a desktop computer (OR 0.66, 95% *CI*: 0.44-0.98, $p < .05$). Also when controlling for age, students at regional campuses were found to be less likely to own a laptop computer (OR 0.60, 95% *CI*: 0.40-0.89, $p = .01$). First-generation students, regardless of age, were also found to be less likely to own a laptop computer (OR 0.61, 95% *CI*: 0.43-0.87, $p < .01$), as were Pell-eligible students (OR 0.67, 95% *CI*: 0.46-0.97, $p < .05$).

Laptop ownership varied based on several demographic categories. Black/African American respondents were 41% as likely to own a laptop when compared to their white peers, and just 28% of Hispanic/Latino respondents owned a laptop in comparison to white respondents. Accordingly, these two groups showed a significantly increased dependence on a Chromebook in lieu of a computer: Black/African American students were over four times as likely and Hispanic/Latino students were seven times as likely to own a Chromebook only and not a laptop or a desktop computer. A respondent's first-generation status also appeared to influence their laptop ownership; first-generation respondents were much less likely to own a laptop than respondents with a family history of college attendance.

Table 4. Demographic factors of device ownership (odds ratios) (*n* = 2041)

Demographic	Desktop	Laptop	Tablet	Chromebook only (no monitor)	Laptop only (no monitor)	Desktop only (one monitor)
Gender (ref. M)						
F	0.34***	1.10	1.36**	2.12	1.75***	0.44*
Age (ref. 18-21)						
22-25	1.45**	1.47	1.27	0.25	0.75*	0.98
26-35	1.84***	1.34	2.09***	0.27	0.41***	0.80
36-45	2.49***	0.77	2.24***	1.31	0.40***	2.04
46-55	2.86***	0.65	2.42***	1.65	0.20***	4.35*
56+	7.32***	0.44	2.23*	1.34	0.11**	7.00*
Ethnicity (ref. White)						
Asian	0.97	0.52	0.91	1.52	0.93	2.62
Black/African American	0.77	0.41*	0.81	4.25**	1.10	2.35
Hispanic/Latino	0.76	0.28***	0.93	6.99***	0.77	2.90
Two or more	0.69	0.72	0.93	1.02	1.30	1.16
Unknown	1.62	0.50	1.06	-	0.19*	10.78**
Enrollment Type (ref. FT)						
Part-Time (<12 cr. Hours)	1.83***	0.70	1.55***	1.43	0.45***	3.03**
Campus Type (ref. Core)						
Urban	1.06*	1.03	1.01	0.98	0.85	1.06
Regional	1.35*	0.59	1.09	2.65*	0.88	1.95
Satellite	1.34	0.57**	0.97	3.20	0.87	5.84
International student						
Yes	0.75	0.78	1.19	-	0.75	0.80
First-generation student						
Yes	1.15	0.60**	0.93	1.79	1.12	1.03
Pell-eligible						
Yes	0.88	0.71	0.74**	2.33*	1.30*	0.88
Classification (ref. UG)						
Graduate	1.56***	1.43	1.75***	0.33*	0.48***	1.02
Professional	0.69	3.59	3.09***	-	0.45***	-
Living status						
Off-campus	1.72***	1.01	1.22	1.05	0.69	1.63
Hours Worked/wk (ref. 0)						
1-10	1.06	1.09	1.27	1.26	1.07	0.55
11-20	1.14	1.23	0.89	0.70	1.02	0.94
21-39	1.28	1.05	1.21	1.38	0.93	0.65
40+	2.21***	1.01	1.97***	1.11	0.38***	1.44
Private study space						
No	0.73*	1.12	0.84	0.99	1.61***	0.64

Note. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

The use of a laptop without an external monitor varied based on several demographic conditions. As the age of the respondent increases, so too does the likelihood that the respondent uses at least one external monitor with their laptop computer. Similarly, graduate and professional students (who tend to be older) were far less likely than undergraduate students to use a laptop without an external monitor. Respondents without a private study space were 61% more likely to use a laptop without an external monitor, which indicates that they may have more transient habits related to where they perform their academic work.

5. Discussion and implications

Overall ownership and access to computing devices for students appears to be quite high. Most students (98.3%) own a smart phone and 97.4% report owning or using either a computer or a Chromebook. When examining computers and Chromebooks, laptops were the most widely adopted device type (92.4%), which aligns with previous surveys of a similar nature (Galanek et al., 2018; Gierdowski, 2019a; Reisdorf et al., 2020). However, 2.2% of students use a Chromebook as their primary computer and 2.6% of students do not have a primary computer or Chromebook. Laptop ownership is slightly – not significantly – correlated with age, but students

who are Black/African American, Hispanic/Latino, or first-generation students show statistically significantly lower likelihood of laptop ownership. These demographics are often correlated with lower SES and, consequently, lower rates of technology ownership (Banerjee, 2020; Gonzales, 2014; Reisdorf et al., 2020).

Tablets appear to be a supplementary computing device; they are owned by just 35.1% of students and fewer than 1.0% of students report using a tablet in lieu of a computer or Chromebook. Female students tend to adopt tablets at higher rate than males, and ownership of tablets increases with a students' age and number of hours worked. Students who are eligible for Pell Grants are less likely to own a tablet, but the devices are more prevalent with graduate and professional students. These findings are supported in previous studies that show cost is a major factor in computer equipment decisions for students (Reisdorf et al., 2020) and that students prioritize the purchase of a phone and a computer over that of a tablet (Elliott, 2022).

The use of Chromebooks by students in higher education is a relatively recent phenomenon but one that should be of particular interest to IHEs. The increased presence of Chromebooks on campus can be likely be attributed to several factors: cost, access, and prior use. Chromebooks are generally less expensive than other laptop computers which may indicate why they are more popular with Pell-eligible students, students of ethnicities correlated with lower SES, and the regional campuses. However, the COVID-19 pandemic and the transition to online learning resulted in the increased use of computer-based education for students in K-12 schools. The younger students in this survey – those that were most recently in K-12 schools – may simply be more comfortable with the Chromebook interface based on their previous experience or may even be using the same devices that carried them through the end of their secondary school experience during the COVID-related transition to online learning.

Although Chromebooks allow access to any compatible web-based learning technology, their limited operating system can present barriers when students are required to install or use specialized software for their academic work. MATLAB, for example, cannot easily be installed directly on a Chromebook (Vivirito, 2013; Mitchell, 2018). 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 a virtualized environment. Similarly, students working on a Chromebook would be relegated to using the online version of Microsoft Office products as they cannot install the native applications. This could impact students who are expected to use advanced features that are not available in the web-based Office 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 majority of students report working on a single computer screen when performing their academic work. Of students who own a laptop as their only non-mobile computing device, 79.6% use the laptop screen alone. Students using Chromebooks are even more likely to use the screen of the device without another monitor. Given that students are required to engage with multiple digital materials while conducting their studies – the LMS, electronic texts, and video resources, just to name a few – they may find difficulties in their ability to reference multiple resources simultaneously with such limited viewing area. A student interviewed by EDUCAUSE during the pandemic reported that they had to drop a class because the online course "…required Photoshop, Zoom, and a photo editor app running simultaneously," which the student's computing ecosystem could not support (Gierdowski, 2021). Further study is needed to determine if students' academic performance can be positively impacted with additional monitors or screen area. However, given the high percentage of students who have access to a computer or Chromebook, institutions may wish to consider replacing some of their existing computing infrastructure to provide students with peripherals (such as docking stations and external monitors) that allow them to enhance their experience when using their personal devices. Regardless, institutions, instructors, and designers should be aware of the limited viewing area available to most students when designing their instructional resources and curriculum. Some students may not be able to fully engage in activities without moving between windows or enlarging the digital content.

6. Conclusion

This study analyzes the results of a survey of students at a large, public IHE in the midwestern United States. The purpose of the study is to provide an up-to-date overview of the personal computing ecosystems in use by students in higher education so that instructors, instructional designers, and institutions can align their pedagogies with the technology available to their students. The results demonstrate that students generally own or have access to an array of computing devices with which they can conduct academic work, but a student's specific computing ecosystem is correlated with several demographic factors. Smart phones and laptop

computers are the students' primary computing devices and most students (79.6%) who use a laptop do so without an external monitor. Students in demographic groups that correspond with lower SES show lower rates of laptop ownership and a higher likelihood of using a Chromebook to complete their academic work. First-generation and Pell-eligible students have fewer computing resources than their counterparts, as do students who study at the smaller satellite campuses in the system in this study. Age was found to be a significant factor in the computing devices owned by students; as students get older they appear to acquire additional or improved computing resources, including tablets, desktop computers, and external monitors.

6.1. Future work

Although this research provides a thorough examination of the personal computing ecosystems at the study site, it makes no attempt to compare the students' personal devices on their academic achievement. Student devices may not necessarily be the determinant between academic outcomes, but the demographic breakdowns detailed here should provide a foundation for work related to the academic achievement of specific subgroups of students. Additionally, while information about ownership and access to devices is important, more work is needed to study the impact of device ownership in conjunction with the environments in which those devices are used. It would be worthwhile to compare students with transient computing ecosystems and habits to their peers with more robust (but less portable) setups to determine if this is a factor in academic outcomes.

Very little work exists that compares learning outcomes between students using different numbers of screens. The few studies that directly compare single- and multiple-monitor configurations show that the use of multiple monitors may reduce cognitive load (Miller et al., 2020) and support improved student learning (Hsu et al., 2012; Lanir et al., 2010). This is an area ripe for study.

Finally, the delineation between mobile devices, "computers," and Chromebooks in this study should further the notion that the student use of non-traditional devices in higher education is increasing to the point where their use must be seriously considered by IHEs and instructional designers. Studies that compare student outcomes when using these different device families – whether or not the study controls for demographic factors – may be able to reveal any potential disadvantages students face when using different types of primary computing devices. Chromebooks in particular may pose a challenge to students. Students in introductory courses may be using web-based versions of applications whose features and behavior can differ from the instructional materials provided. Chromebooks may also hinder students in advanced courses that require significant computing resources and/or specialized software.

6.2. Limitations of the study

Many of the demographic categories described in this study, including gender, race/ethnicity, and international student status, came from institutional data that was collated with the survey results. This institutional data, unfortunately, has a limited number of categories available – particularly for the gender and race/ethnicity categories. Survey respondents were not provided the opportunity to self-identify their gender identity, race, or ethnicity which prevented a more granular analysis of individual student responses for these demographic items. The author sincerely regrets that this is the case.

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