

National Income, Political Freedom, and Investments in R&D and Education: A Comparative Analysis of the Second Digital Divide Among 15-Year-Old Students

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Accepted: 9 November 2018 / Published online: 17 November 2018 © Springer Nature B.V. 2018

Abstract

Digital technology has become an indispensable component in education around the world. Despite its growing importance, a gap in students' digital skills and usage based on their socioeconomic status-known as the second digital divide-has been identified in a wide range of countries. Using data from the 2009 OECD Programme for International Student Assessment, we consider two aspects of the second digital divide for 15-year-olds across 55 countries: the gaps in use of educational software at home and Internet literacy. Specifically, we ask whether national income, political freedom, and national investments in research and development (R&D) and secondary education are associated with the second digital divide. We find that national income predicts the digital divide and that national investments have differential effects depending upon a country's income. R&D spending reduces the socioeconomic gap in educational software use only in low-income countries. Educational expenditures reduce the Internet literacy gap in high-income countries while exacerbating it in low-income ones. Additional analyses suggest that income inequality increases the digital divide, but like political freedom, the effects become non-significant when national income is considered. We conclude by discussing the implications of these findings for policymakers interested in reducing the digital divide.

Keywords Second digital divide $\cdot R \& D \cdot Educational expenditures \cdot PISA \cdot Multilevel modeling$

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1 Introduction

In recent decades, the rate at which digital technology has penetrated educational settings throughout the world has been staggering. Familiarity with hardware such as desktop and tablet computers, and software such as word-processing programs and Internet search engines is rapidly becoming a prerequisite to success. However, despite the progressive spread of new technology, a number of inequalities have been identified. The first disparity, referred to as "the first digital divide," concerns the socioeconomic inequality between people who have access to digital technology, with more affluent people having greater digital access. Recent studies have found a worldwide decline in the digital access divide, even within less-developed countries. This is largely due to the intentional efforts of educators, policymakers, and entrepreneurs (Erichsen and Salajan 2014; Spring 2008). The second disparity, known as the "second digital divide", concerns the socioeconomic disparity in *digital use* for learning and productive purposes (Attewell 2001). In sum, students with higher socioeconomic status are more likely to use computers for educational purposes. This inequality exists even after digital access equality has been achieved, and it remains a problem for both high- (Hargittai and Hinnant 2008; Peter and Valkenburg 2006) and lowincome countries (Drori 2010; ITU 2011). This raises the question: Why does the second digital divide persist across countries of different economic standing, especially affluent nations that have largely eliminated the access divide?

Understanding the cause of the second digital divide, as well as identifying possible solutions to it, is increasingly relevant as digital technology becomes further ingrained into global education systems. Schools are increasingly posting assignments online and requiring students to use computers for schoolwork (OECD 2011). Lacking parental guidance, students of lower socioeconomic status (SES) are more likely to use digital devices for social networking and gaming and thus are less prepared for academic assignments than their higher-SES peers, whose parents tend to guide their children in using digital technology for productive purposes (Attewell 2003; van Deursen and van Dijk 2014). This socioeconomic gap in digital use may reinforce or even exacerbate existing educational and social inequalities. Earlier research suggests that several demographic features, such as race and family structure, are related to the digital divide (DeBell and Chapman 2006; Notten et al. 2009), but SES remains the most influential individual-level factor in cross-national research on digital use (OECD 2011, 2015).

Moreover, research highlighting school-level explanations suggests that low-SES students tend to use computers for remedial purposes, whereas their high-SES peers are more likely to enroll in advanced computer classes and use technology for innovative purposes (Becker 2000; Robinson 2014). In the U.S., students who attend schools in economically advantaged neighborhoods are 1 year ahead of those attending less privileged schools when it comes to online research and comprehension skills (Leu et al. 2014). This again shows that the digital divide by SES remains persistent when schools fail to provide sufficient computer-related resources and courses to help develop the digital skills of underprivileged students (Natriello 2001).

The relationship between SES and digital use may also depend on national context. Previous research has identified several country-level factors that are associated with the first digital divide, including economic development (Guillén and Suárez 2005; Norris 2001; Robison and Crenshaw 2010), digital infrastructure development (Dutton et al. 2004), and the degree of democracy in government (Corrales and Westhoff 2006; Robison and Crenshaw 2010). However, little empirical research has examined how country-level contextual factors may moderate the second digital divide, including how various nation-level investments might affect the relationship between family SES and digital use.

To begin to address these gaps in the literature, we examine the second digital divide among 15-year-old students in 55 countries, using data from the 2009 Programme for International Student Assessment (PISA) survey. We define the second digital divide as the effect of socioeconomic status on two proxy measures of digital use—inequality in computer use for educational purposes at home and Internet literacy. Broadly, we ask how institutional arrangements of countries, such as macro-economic conditions, public policies, and business practices, affect the level of the second digital divide. Following previous research on digital inequality, we focus first on the role of national income and political freedom in explaining cross-national variation in the second digital divide. Because our study focuses on youths, we go on to explore two types of national-level investments that have received much attention in comparative educational research (Dale 2005; Erichsen and Salajan 2014; Spring 2008) and studies of global digital inequality (Drori 2006, 2010; Dutton et al. 2004; Norris 2001) and may be related to the second digital divide among 15-year-olds: investment in research and development (R&D) and national expenditures on secondary education.

To date, comparative education and stratification research has focused primarily on achievement gaps, but students' digital skills and literacy are an important aspect of inequality in the digital era. This paper builds on previous research and makes several contributions to the literature. First, past studies have focused on the first digital divide for adults. We examine the second digital divide among 15-year-old students—a section of the population for which the digital divide may prove most important. Second, previous research has focused primarily on wealthy countries, especially the U.S. (DiMaggio et al. 2004). We go beyond these studies by examining an economically diverse set of countries. Finally, the existing research has focused on individual-level explanations for the digital divide (Robison and Crenshaw 2010). We consider how the influence of family SES—an important individual-level factor—varies cross-nationally. Taken together, we believe this research provides insight into some of the key factors associated with the second digital divide, which may prove valuable for countries seeking to become successful players in the global knowledge economy and to increase the digital literacy of their populations (Spring 2008).

2 Individual-Level Factors Associated with the Digital Divide

Economic globalization and the emergence of the *information society* have dramatically increased competition among individuals seeking access to a limited number of opportunities. However, middle-class and elite families have been able to mobilize various resources, including digital learning resources, "to stand out from the crowd" (Brown 2013, p. 683). This process of positional competition has increased the importance of digital technology for individuals seeking to increase their knowledge and establish social networks that can foster social mobility (DiMaggio et al. 2004; DiMaggio and Cohen 2005). If the distribution of technology is unequal, it may only exacerbate already existing inequalities. Earlier research suggests that students from racial-minority or single-parent families are less likely to access the Internet at home than their non-minority peers or those living in two-parent households (DiMaggio et al. 2004; Notten et al. 2009). However, when socioeconomic background is controlled for, the effects of race and family type are reduced significantly

(DeBell and Chapman 2006; OECD 2011; Peter and Valkenburg 2006). In other words, SES has been found to be the most influential predictor of the digital divide (OECD 2015).¹

Previous research offers several clues as to why SES is an important factor when studying the digital divide. For example, recent studies from the United States (Hargittai and Hinnant 2008) and Switzerland (Bonfadelli 2002) suggest that highly educated adults are more likely to do capital enhancing or information-oriented activities online, such as visiting websites about national news, health, and financial information, than their lesseducated counterparts. In Korea, higher-SES adults are more likely to use the Internet for political knowledge (Kim 2008). This disparity may be due, in part, to the conscious decisions made by higher-SES adults who are seeking to improve or maintain their social status, but high SES is also related to higher levels of education in general, which can mediate the relationship between SES and digital use.

While much of the previous literature has focused on adults, the digital divide among school-aged children and adolescents is equally, or even more, important. The way that students use digital technology can influence their learning as well as their non-academic behavior (see Attewell et al. 2003; Fuchs and Wossmann 2004), and the digital inequalities generated during youth are likely to be carried into adulthood. For example, research from Britain (Livingstone and Helsper 2008) and Australia (Smith et al. 2013) has shown that students with highly educated parents are more likely to use computers or the Internet for learning. By comparison, in the Netherlands (Peter and Valkenburg 2006) and Hong Kong (Leung and Lee 2012), lower-SES students use the Internet primarily for gaming or social networking. In part, this can be attributed to parents' investment choices when purchasing technology (e.g., digital devices with more functionality, useful software, and high-speed Internet) as well as their active involvement in their children's use of the technology, such as sitting with and supervising their children's computer use (Attewell 2001).

3 Country-Level Factors Associated with the Digital Divide

In the final decades of the 20th century, there were just a few national-level efforts to promote the use of technology in education (Erichsen and Salajan 2014; U.S. Department of Education 1996). Since then, the quantity and urgency of these efforts has increased dramatically (Spring 2008), often inspiring competition among the most developed nations (Erichsen and Salajan 2014). Studies in less-developed countries indicate a growing commitment to increasing digital literacy as well, but their efforts are often limited by the highly unequal global distribution of resources (Drori 2006, 2010; UNESCO 2015). To further examine how this global inequality affects a country's ability to bridge the digital divide among students, we first consider how national income and political freedom—two strong predictors of the first digital divide—may influence the second digital divide. Then, we focus on national investments in R&D and secondary education because they may be relevant for the youth population examined in this study. Furthermore, unlike political freedom and national income, which are resilient features of economies, national investments

¹ Research from Australia (OECD 2011) and Cyprus (Milioni et al. 2014) suggests a "reverse digital divide" between immigrants and nonimmigrants; that is, there is a "compensatory or remedial use of the Internet (Milioni et al. 2014, p. 333)" by racial minority immigrants in order to overcome their existing racial and social barriers.

can fluctuate more rapidly and thus may be capable of affecting digital inequality in the near term.

3.1 National Income

National income is believed to be one of the most influential factors in Internet diffusion (Guillén and Suárez 2005; Norris 2001), which is supported by the persistently low rates of computer ownership and Internet access in poor countries (Drori 2006; ITU 2011). Without widespread diffusion of digital technology, access is generally restricted to the higher-SES members of society. In this way, national income can moderate the level of the digital divide by reducing the disparity in access between the more and less affluent.

As economic development improves people's living conditions, low-SES people spend a smaller proportion of their income on necessities (e.g., food, housing) and thus have more money to spare for digital devices. Moreover, economic growth can promote both public expenditures on and private investments in Internet infrastructure (e.g., high-speed Internet landlines and community e-service) and stimulate competition among Internet service providers, which can reduce the price charged for access (Hilbert 2010). Whether due to increases in disposable income, improved digital infrastructure, or increased competition, economic development has been shown to reduce the first digital divide by improving Internet access rates for those on the low end of the SES spectrum. While there are no direct comparative studies of the second digital divide among youths, we expect a similar relationship between national income and the gap in digital use. That is, increases in national income should promote the use of digital technology for learning and productive purposes among low-SES students, leading to reductions in the level of the second digital divide:

Hypothesis 1 National income will have a negative association with the second digital divide; that is, increased national income will reduce the socioeconomic gap in digital use.

3.2 Political Freedom

Distinct from national income, political freedom may also influence the digital divide (Norris 2001). In less-democratic or authoritarian societies, the government may prevent the diffusion of online networked technology by monitoring people's online activities and blocking Internet access in public spaces such as libraries or schools. The fear of government reprimand and the lack of digital technology at home are likely to work together to reduce digital use by the less-privileged in authoritarian societies. In contrast, basic civil liberties such as freedom of speech and press are protected in democratic states, opening the door to more public investments in digital access points at schools and libraries. Furthermore, political freedom can also spur the growth of private investment in new information technologies, which may reduce the cost of Internet access, and make it more readily available to the less affluent (Robison and Crenshaw 2010).

The intuitiveness of this argument notwithstanding, some scholars suggest that economic factors tend to outweigh political freedom when it comes to the digital divide. For example, Corrales and Westhoff (2006) explain that not all authoritarian governments are against Internet diffusion. In particular, authoritarian states that are market oriented have fewer restrictions on Internet use. In line with this argument, Robison and Crenshaw (2010) demonstrate that democratic governance and political stability only affect Internet development when a country's economy is depressed or stagnant. Again, these studies on political freedom have focused only on the first digital divide, with little attention to the second, but we see no reason to anticipate that the findings would be different. Thus, based on these accounts, we propose that:

Hypothesis 2 Political freedom will have a negative association with the second digital divide among students; that is, increased political freedom will reduce the socioeconomic gap in digital use.

3.3 R&D

Many scholars have referred to the rapidly changing world economy as the new "knowledge economy," characterized by massive information flows, extensive adoption of new information technology, and rapid advances in science and technology (Dale 2005; Powell and Snellman 2004; Spring 2008). Spending on R&D, by both the public and the private sectors, is indicative of a country's efforts to become more competitive and innovative and to play an active role in the knowledge economy. However, the benefits of national-level investments in R&D are not limited just to the economy. R&D produces spillover effects that can affect many other areas of social life, including agriculture, medicine, entertainment, and, most relevant to our study, education (Drori 2006).

R&D spending is often piloted in educational settings with the aim of improving educational outcomes of disadvantaged students and enhancing the overall quality of education (Snow 2002; Spring 2008). Heyneman and Loxley (1983, pp. 1183–1184) note that "the areas of the world with comparatively large amounts of research and development capital tend also to be the areas where educational paradigms are invented." For example, the Australian government created a platform that enables schools to share and distribute educational resources through online portals (Education Services Australia 2012). In the U.S., the invention of cyber schools is regarded as a new opportunity for students who have failed in the conventional school system (Hill 2010). Additionally, major corporations throughout the world, including Microsoft, Intel, Hewlett-Packard, and AT&T, have donated a great deal of computer equipment to underserved schools (Norris 2001). For less-developed countries, Information and Communication Technologies for Development (ICT4D) is a global initiative that works closely with governments, universities, public schools, and private organizations to reduce digital inequality (UNESCO 2016). Considering these findings, we offer the following hypothesis:

Hypothesis 3 National investments in R&D will have a negative association with the second digital divide; that is, increased investment will reduce the socioeconomic gap in digital use.

3.4 Educational Expenditures

Globally, the level of spending per pupil on primary and secondary education has surged over the past two decades (Baker et al. 2002), marking a substantial increase in national investments in the production of human capital. This investment affects the educational outcomes of students, particularly those from less affluent households (Chiu 2010). As a result, many scholars have explored the relationship between public education expenditures

and the educational attainment gap between low- and high-income children (for results from the U.S., see Mayer 2001; for results based on international comparisons, see Vegas and Coffin 2015).

Public expenditures in educational settings may level the playing field for students across socioeconomic backgrounds and subsequently reduce the second digital divide. Qualitative studies suggest that insufficient digital access and lack of guidance in the use of digital technology for less-affluent students contributes to substantial levels of inequality in digital use (Goode 2010; Natriello 2001; Robinson 2014). For instance, Natriello (2001) points out that racial minorities and socioeconomically underprivileged students in the U.S. are more likely to attend schools with extremely low educational quality and severe budget deficits that contribute to their deficiency in digital skills.

This suggests that the digital divide is, in part, due to the unequal distribution of educational resources among schools, including the availability of computer programs. From this line of reasoning, it is logical to suppose that government investments in digital access and the creation of opportunities for disadvantaged students to develop their digital skills would lead to a reduction in the second digital divide (Gamoran 2001). Considering the national variation in public spending on education, even among countries with similar economic standing, we propose the following hypothesis:

Hypothesis 4 Investments in secondary education will have a negative association with the second digital divide; that is, increased investment will reduce the socioeconomic gap in digital use.

3.5 Differential Effects by National Income Level

In studying the second digital divide, it is important to account for the vast diversity of life experiences and educational trajectories in different regions of the world, especially noting the institutional variation between developed and less-developed countries (Buchmann and Hannum 2001; Juárez and Gayet 2014). Since we are focusing on school-aged youths, we note that national investments in human capital may be more effective at reducing the educational achievement gap in high-income countries that already provide basic educational resources, including learning materials and teacher training (Vegas and Coffin 2015). Conversely, the high levels of social inequality and poverty that exist in low-income countries can limit the benefits of educational investments to only the most affluent students (Juárez and Gayet 2014). For example, recent research in Moldova suggests that poverty and lack of employment opportunities can affect how children learn at home and in school. There is also a shortage of qualified teachers, as many teachers emigrate to other countries for work (Worden 2014). In addition, the inability of many poor countries' governments to provide educational leads to an increased reliance on private schools, which has greatly limited educational opportunities for poor and underprivileged students (Chankseliani 2014).

Conversely, the marginal utility of further human capital investments in high-income countries may be diminished because of already high levels of investment (Buchmann and Hannum 2001). The persistence of educational inequalities in affluent countries, despite their high levels of investment in education, offers some support for this argument (Hannum and Buchmann 2005; Raftery and Hout 1993). Considering these possibilities, we explore how the association between national investments in R&D and secondary education and the digital divide may vary depending upon the national income of a country. We offer the following two competing hypotheses:

Hypothesis 5a The effects for R&D spending and educational expenditures in bridging the socioeconomic divide in digital use will be smaller for students in low-income countries.

Hypothesis 5b The effects for R&D spending and educational expenditures in bridging the socioeconomic divide in digital use will be greater for students in low-income countries.

We explore these hypotheses by creating interaction effects between our two nationallevel investment variables—R&D spending and educational expenditures—and the national-level measure of income. These interaction effects will reveal any variations in the findings of our main models that could be attributed to levels of economic development. We see no theoretical reason to pursue similar interactions for political freedom, but results from such models are available upon request.

4 Data, Measures, and Methods

4.1 Data

Our analyses use data from the 2009 Programme for International Student Assessment (PISA) survey, collected by the Organization of Economic Cooperation and Development (OECD). PISA is a nationally representative triennial survey, begun in 2000, that assesses the academic performance, problem-solving skills, and digital technology use of 15-year-old students, regardless of grade level. The 2009 survey is uniquely suited to examining the second digital divide because it includes a variety of questions related to students' behaviors and attitudes regarding digital use. The timing of the 2009 survey also coincides with a period of increased use of the Internet worldwide. Further, the 2009 student questionnaire contains a unique set of questions related to Internet literacy, referred to as online reading (OECD 2012), that are not available from other cycles of the student questionnaire. While the original sample contains 73 countries, we restrict our analyses to 55 countries because of missing data on country-level variables. This sample size is large enough to generate reliable country-level estimates (multilevel models with fewer than 35 countries can yield underestimated country-level variations) (Bryan and Jenkins 2016).

Using the International Telecommunication Union (ITU 2011, p. 27) categorization, our paper includes 8 low-income countries, 17 medium-income countries, and 30 upperand high-income countries.² In our analyses, we adopt this income classification, and to facilitate ease of discussion, we identify the categories as: low-income countries, middleincome countries, and high-income countries. While our analyses include countries from a wide range of economic backgrounds, it should be noted that a large proportion of countries that participated in PISA are from the developed world—a problem in most international data sets.

 $^{^2}$ The gross national income per capita for low-income countries is below \$4570 in U.S. dollars; medium-income countries are between \$4571 and \$14,090; and upper- and high-income countries are above \$14,091.

To preserve cases, we use multiple imputations (m = 10) for missing values in the individual-level control variables (Royston et al. 2009). The original sample size of students across 55 countries is 402,671. Dropping missing cases in the dependent variables and the key independent variable—family SES—leads to final sample sizes of 391,261 and 398,681 cases for the two dependent variables discussed below. In the "Appendix", Table 5 reports the descriptive statistics for key individual-level variables in each of the 55 countries,³ and Table 6 reports the values of country-level variables for the 55 countries.⁴

4.2 Dependent Variables

In this research we focus on the association between country-level variables and the second digital divide, operationalized as the extent to which family SES affects two proxy measures for digital use—students' use of computers for educational purposes at home and their Internet literacy. Beginning with computer use for educational purposes at home, two measures are available in PISA. The first is a composite IRT score of *digital use for schoolwork at home*, available for 37 countries. The second is a dichotomous variable of *whether students use educational software at home*, available for 55 countries. Both variables are reasonable proxies for digital use, but the second measure is more narrowly defined. Supplementary analyses using the two measures as dependent variables show similar effect patterns (see Fig. 3 in the "Appendix"). We opt to use the second measure because it allows us to examine a substantially larger and more diverse sample of countries (55 vs. 37).

Internet literacy, a second proxy for digital use, is measured by a composite scale of five online reading activities (α =.79): reading online news, using an online dictionary or encyclopedia, searching online information to learn about a particular topic, taking part in online group discussions or forums, and searching for practical information online (e.g., schedules, events, tips, or recipes).⁵ We focus on these five items because each has been found to be positively related to students' offline reading proficiency (OECD 2011). The combination of these items indicates student familiarity with reading text on the screen, sharing information and exchanging ideas, and interacting with others in a digital context. The variable is standardized with a mean of 0 and a standard deviation of 1.

4.3 Individual-Level Variables

Our key individual-level independent variable, *family SES*, is based on the PISA-created Index of Economic, Social, and, Cultural Status (OECD 2012), which is the most common measure of SES in studies using PISA data. The variable is a combination of three components: (1) parental occupation status, from the international socio-economic index of occupational status (ISEI) (Ganzeboom et al. 1992), (2) parental education in years, and (3) an index of household possessions, such as a room for the child, owning classical literature, a

³ To account for the possibility that countries with large sample sizes may disproportionately affect parameter estimates, we run supplementary analyses with a variable measuring country sample size and find our results to be unchanged.

⁴ Following previous studies (Chiu 2010; Decancq and Schokkaert 2016), we present the unlogged values in the appendix to give the reader a better sense of the actual range of values for the country-level variables.

⁵ Seven online activities are listed in the questionnaire. We excluded two of these activities—reading emails and chatting online—as they are less relevant to students' online literacy and reading proficiency (OECD 2011).

desk for the child to study at home, and the number of books at home. To ease interpretation of the results, the variable is standardized to have a mean of 0 and a standard deviation of $1.^{6}$

In addition, we include four individual-level control variables that were collected through the PISA survey. *Gender* controls for the potential digital gap between male and female students (male = 1). To control for the effect of immigration status, we include two dummy variables—*first-generation immigrant* and *second-generation immigrant*—with *non-immigrant student* as the reference category. To control for differences in language used by immigrant students, we include a dummy variable—*foreign language use at home*—with *primary language is the same for home and school* as the reference category. We include this control because students who are not native speakers of the language used at school may be academically disadvantaged compared to native-speaking students. To control for family structure, we include two dummy variables—*single-parent family* and *other family*—with *two-parent family* as the reference category. We assume that omitting these four control variables induces common-cause confounding bias because they may affect both our key independent variable (family SES) and our outcome variables (Elwert and Winship 2014).

4.4 Country-Level Variables

To examine cross-national differences in the second digital divide, we compile a set of country-level factors from a variety of publicly available sources. To measure a country's national income, we use *Gross Domestic Product (GDP) per capita*, in thousands of 2009 purchasing power parity dollars, obtained from the World Bank's World Development Indicators (WDI) (2015a). We use the *composite polity score* to measure the level of political freedom. This is a combined democracy-autocracy index developed by Marshall et al. (2010). The scale ranges from -10 (strongly autocratic) to 10 (strongly democratic). To measure a country's investment in R&D and secondary education, we include R&D as a percentage of GDP from the WDI (2015a) and secondary educational expenditures as a percentage of GDP from the World Bank's Education Statistics (2015b). All of the country-level data are from 2009—the year that the individual-level PISA data were collected.⁷ Natural log values are used for all country-level variables to account for the skewness of the distribution (Ruiter and van Tubergen 2009) and to address potential curvilinear relationships (Heisig 2011).⁸ Table 1 presents descriptive statistics and coding for all variables used in the analyses.

4.5 Analytical Strategy and Statistical Methods

We use multilevel models to analyze the effects of country-level factors on the two dependent variables and to account for the interdependent variations caused by the clustering of

⁶ Some studies use the number of books at home as a proxy for family SES or social class (Carnoy and Rothstein 2013). We consider this alternative in supplementary analyses and find the results to be substantively the same.

⁷ For countries that have missing data on country-level variables in 2009, we utilize data from the closest adjacent year in which data are available (see Table 6 in the Appendix).

⁸ Because the composite polity score ranges from -10, to 10, we take a linear transition by adding 11 before logging to ensure that all values are positive.

Variable	Mean/proportion	SD	D Description/coding	
Individual-level variables				
Use of educational software at home	0.49		1 = yes, 0 = no.	
Internet literacy	0.00	1.00	Standardized variable based on five online reading activities (Cronbach's α = .79): reading online news, using an online dictionary or encyclopedia (e.g., wikipedia), searching online information to learn about a particular topic, taking part in online group discussions or forums, and searching for practical information online (e.g., schedules, events, tips, or recipes). Response categories from lower to higher values are: "I don't know what it is", "never or almost never", "several times a month", "several times a week", and "several times a day".	
Family SES	0.00	1.00	Standardized and PISA-created index of economic, social, and cultural status (OECD 2012), including: parental occupation status expressed as the index of ISEI, parental education in years, and an index of household possessions (e.g., a room for the child, possessions of classical literature, a desk for the child to study at home, and the number of books at home).	
Male	0.49		1 = male, $0 = $ female.	
First-generation immigrant	0.04		1 = yes, 0 = no. Reference group = non-immigrant student.	
Second-generation immigrant	0.05		1 = yes, 0 = no. Reference group = non-immigrant student.	
Foreign language use at home	0.11		1 = yes, 0 = no.	
Single-parent family	0.17		1 = yes, 0 = no. Reference group = two-parent family.	
Other family	0.04		1 = yes, 0 = no. Reference group = two-parent family.	
Country-level variables (all natural log transfe	ormed)			
GDP per capita	3.08	0.68	Gross domestic product per capita in thousands of 2009 purchasing power parity (PPP) dollars. The unlogged value ranges from 3.54 to 76.85.	
Composite polity score	2.86	0.42	Composite variable based on two variables: democracy and autocracy. The scale ranges from -10 (strongly autocratic) to 10 (strongly democratic). Before it is natural log transformed, all values are transferred into positive integers by adding 11. The unlogged value ranges from -7 to 10.	
R&D as % of GDP	-0.14	1.08	Research and Development including both public and private expenditures that cover basic research, applied research, and experimental development. The unlogged value ranges from .05 to 4.15.	

Table 1 Descriptive statistics and variable descriptions in the analysis

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Table 1 (continued)

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Variable	Mean/proportion	SD	Description/coding
Secondary educational expenditures as % of GDP	0.56	0.40	Total government expenditures on secondary education from the local, regional, and central government and transfers from international sources. The unlogged value ranges from .64 to 3.63.

Data Source All individual-level variables are from the Programme for International Student Assessment (PISA) 2009; GDP per capita and R&D are compiled from the World Bank's World Development Indicators (2015a); composite polity score is from Marshall et al.'s (2010) Polity IV Project; secondary educational expenditures are from the World Bank's Education Statistics (2015b)

To preserve cases, multiple imputations (m = 10) for missing cases are used for individual-level control variables

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students within countries (Rabe-Hesketh and Skrondal 2008). The multilevel analysis consists of an individual- and a country-level model. At the individual-level, the general form of the models for a student i in country j can be written as,

$$\eta_{ij} = \beta_{0j} + \beta_{1j} (Family SES)_{ij} + \sum_{2}^{k} \beta_{kj} X_{kij} + r_{ij}$$
(1)

The left-hand side link functions η_{ij} are treated differently for binary and continuous outcome variables. For the binary dependent variable—*use of educational software at home*— η_{ii} can be specified as:

$$\eta_{ij} = ln\bigg(\frac{\emptyset_i}{1 - \emptyset_i}\bigg),$$

where \emptyset_i is equal to P(y=1|X), making the model a multilevel logistic model. For our continuous dependent variable—*Internet literacy*— η_{ij} is equal to y. β_{0j} is the individual-level intercept, adjusted for family SES and other individual-level control variables. β_{1j} is the coefficient of family SES. r_{ij} is the unexplained variance for individual *i* in country *j*. At the country-level, we assume:

$$\beta_{0j} = \gamma_{00} + \sum_{1}^{k} \gamma_{0k} Z_{kj} + \mu_{0j}$$
⁽²⁾

$$\beta_{1j} = \gamma_{10} + \sum_{1}^{k} \gamma_{1k} Z_{kj} + \mu_{1j}$$
(3)

where the intercept and the coefficient to family SES slope are allowed to randomly vary across nations.⁹ Z_{1j} to Z_{kj} indicate a set of country-level variables. All continuous country-level variables are centered at the grand mean, so that γ_{00} represents the grand mean of the intercept and γ_{10} indicates the grand mean of the family SES slope for countries whose country-level variables are set at the average values. The main focus of this paper is to examine the association between national contextual factors and the digital divide, measured as the slope of family SES regressed on the two outcome variables (Eq. 3).

Our analyses proceed in three stages. In the first stage, we use logit and linear regressions, respectively, for *educational software use at home* and *Internet literacy*, and estimate the models separately in each of the 55 countries. Based on these models, we use graphs to visualize how the effect of family SES on the two digital use measures varies across countries of different economic standings. Next, we use multilevel models to formally examine the country-level variation in the second digital divide. To test our hypotheses that national income, political freedom, R&D investment, and secondary educational expenditures reduce the second digital divide, we estimate the effects of these national indicators on the two dependent variables and the slopes of family SES. Finally, we examine whether the

⁹ To avoid over-parameterization, we do not consider the random slopes of other individual-level variables. In models not shown, we find the inclusion of additional random slopes does not influence the main results reported here. Additionally, we find family SES to be much more important than other variables in capturing cross-cluster heterogeneity. These models are available upon request.

effects of national investments in R&D and secondary education on the family SES slopes differ across low-, middle-, and high-income countries. Based on the estimated models, we calculate the predicted SES slopes for the 55 countries and present the results in graphs.

5 Results

Figure 1 illustrates the variations in the second digital divide (more specifically, the relationship between family SES and our two proxy measures for digital use) across three country-level income groups using the results of separate regression models for each country. Overall, the effect of family SES on the two outcomes differs substantially across national income levels. On average, the slopes of family SES among low-income countries are steeper than the slopes in most middle- and high-income countries (for example, compare the SES slopes between Georgia, Lithuania, and Spain when predicting Internet literacy). This suggests that the second digital divide is more pronounced in poor countries. However, we also see that the slopes of family SES vary among countries with similar wealth, particularly among high-income countries. This suggests that national income can only partially explain cross-national variation in the level of the second digital divide.

Using multilevel modeling, we more formally examine country-level variation in the second digital divide in Table 2. We first note that the intra-class correlation coefficients (ICC) for empty models (models that only include the intercept) are .127 when predicting educational software use at home, and .114 when predicting Internet literacy. In other words, about 11–13% of the variation in the intercept occurs at the country level. While informative, these numbers can only represent the cross-national variation in the intercept. In what follows, we examine how family SES slope—the main focus of our study—varies across countries.

Model 1 shows the effect of family SES on the use of educational software at home in all nations. Among students with average family SES, the predicted probability of using educational software at home is 50% (=1/(1+e{-(-.015+0*.823)})) and for a one-standard-deviation increase in SES, the probability increases to 69% (=1/(1+e{-(-.015+1*.823)})). Model 1 also reveals that the country-level variance in family SES is .056 (p < .01), which suggests a 95% confidence interval ranging from .358 to 1.288 (=.823±1.96* $\sqrt{.056}$) for the SES coefficients. In substantive terms, this means that, excluding the extreme 5% of the two sides, the predicted probabilities range from 58% (=1/(1+e{-(-.015+.358)})) to 78% (=1/(1+e{-(-.015+1.288)})) for students whose family SES is one standard deviation above the mean. This level of variation justifies an examination of the influence of SES on digital use across the 55 countries in this analysis.

Model 2 introduces the individual-level control variables. The estimated effect of family SES decreases only slightly and remains statistically significant (β =.816, p <.01). A one-standard-deviation increase in family SES increases the probability of using educational software at home by 19% (=1/(1+e{-(.097+.816)})-1/(1+e{-(.097)})). Results from the variance components show that the 95% confidence interval for the SES slope ranges from .364 to 1.268, indicating that a one-standard-deviation increase of SES will increase the probability of student use of educational software at home by between 9% and 27% across the 55 countries.

Model 3 presents the effect of family SES on Internet literacy. For each standard deviation increase in family SES, Internet literacy increases by .338 standard deviations (p < .01). After including other individual-level characteristics in Model 4, the



Fig. 1 Regression lines of educational software use at home and Internet literacy. *Note* The left panel contains predicted plots based on logit models. The right panel contains predicted plots based on OLS models. Each model includes individual-level control variables (gender, immigration status, foreign language use at home, and family structure)

	Use of education home ^a	onal software at	Internet literacy ^b		
	Model 1	Model 2	Model 3	Model 4	
Intercept	015 (.082)	.097 (.086)	.034 (.036)	012 (.038)	
Family SES	.823 (.032)**	.816 (.032)**	.338 (.018)**	.342 (.017)**	
Male		139 (.024)**		.070 (.010)**	
Reference group: female					
Immigration status					
Reference group: non-immigrant					
First-generation immigrant		.075 (.040)+		.163 (.033)**	
Second-generation immigrant		.217 (.053)**		.205 (.026)**	
Foreign language use at home		073 (.047)		030 (.038)	
Reference group: primary language is the same for home and school					
Family structure					
Reference group: two-parent family					
Single-parent family		224 (.017)**		003 (.006)	
Other family		229 (.038)**		067 (.018)**	
Variance components					
Between-country intercept variance	.364**	.360**	.072**	.071**	
Between-country family SES variance	.056**	.053**	.017**	.016**	
Within-country variance			.813	.810	
Log-likelihood	- 5,53,994	-5,54,264	-5,24,719	- 5,23,907	
N _{Individual-level}	391,261	391,261	398,681	398,681	

Table 2 Multilevel analyses for the second digital divide with individual-level varial	bles
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Note Number of countries = 55. Robust standard errors are in parentheses. All coefficients are adjusted by multiple imputations for missing cases in the control variables (m = 10). *Log-likelihood* is from imputed dataset m = 1

^aFor an intercept-only model: between-country intercept variance is .479. The intraclass correlation (ICC) is .127

^bFor an intercept-only model: between-country intercept variance is .117. Within-country variance is .913. ICC is .114

**p < .01, *p < .05, +p < .1 (2-tailed)

coefficient for family SES increases slightly to .342. When taking variance components into account, we find that the effect of family SES on Internet literacy ranges between .093 and .591 standard deviations among 95% of the countries in our analysis. Taken together, we conclude that family SES significantly affects both educational software use at home and Internet literacy, but we note that the size of the effect varies substantially across countries (Model 2: μ_{1j} =.053, p < .01, Model 4: μ_{1j} =.016, p < .01). For instance, the effect of family SES in Jordan (SES slope=.542) is approximately four times greater than in Portugal (SES slope=.137). This degree of cross-country variation warrants further investigation and raises the question: which country-level indicators are associated with the digital divide? This is a question with obvious policy implications,

and we will attempt to address it in the next two sections, but not before first reviewing the effects of the remaining individual-level controls included in these models.

Most of the individual-level controls in Models 2 and 4 perform as expected. When controlling for SES and other socio-demographic characteristics, students who are second-generation immigrants have the greatest likelihood of using educational software at home and have the highest level of Internet literacy compared to first-generation students (p < .01, results not shown) and non-immigrants (p < .01). Non-immigrant students have the lowest level of digital use for both outcome variables. Also, speaking a foreign language at home does not significantly affect educational software use at home or Internet literacy. These findings correspond to recent literature that suggests a "reverse digital divide" between immigrants and nonimmigrants (Milioni et al. 2014), but future researchers should further investigate whether this reverse digital divide is observed across different regions of the world.

Compared to two-parent families, students living in single-parent families are less likely to use educational software at home, but have similar levels of Internet literacy. Finally, we note that male students have significantly higher Internet literacy than females, which is consistent with previous studies that have found a tendency for girls to report lower selfassessment of online skills than boys (Hargittai and Shafer 2006). Despite this gender gap in Internet literacy that advantages boys, male students are less likely to report using educational software at home than females (Model 2). This result corresponds with findings from recent studies which find that despite their high rates of computer use, male students are more likely than female students to use computers for non-educational activities, such as gaming (Imhof et al. 2007).

5.1 Sources of Cross-National Variation in the Second Digital Divide

To evaluate cross-national variation in the second digital divide, we estimate multilevel models assessing the effects of country-level variables on the two outcomes as well as the slope of family SES. In Table 3, we first include our measures of national income (GDP per capita) and political freedom (composite polity score) to examine whether the association between economic factors and the second digital divide can be explained by political factors, or vice versa (Model 1 for educational software use at home; Model 4 for Internet literacy). We then test whether R&D and secondary educational expenditures as a percent of GDP affect the second digital divide in use of educational software at home (Models 2 and 3) and Internet literacy (Models 5 and 6).¹⁰ We continue to control for national income and political freedom in these models in order to test whether the effects of R&D and educational expenditures persist net of economic and political forces. All analyses include the same individual-level control variables shown in Table 2. The top half of Table 3 shows the effects of country-level measures on the intercept. The bottom half of the table examines the effects of country-level variables on the slope of family SES (the level of the second digital divide). The differential effects of family SES by R&D and secondary educational expenditures across country-level income groups are further examined in Table 4.

Beginning with educational software use at home, we see in Model 1 that the average effect of family SES is .815. This indicates that a one-standard-deviation increase in family SES increases the probability of using educational software by 19%. The coefficients for

¹⁰ In supplementary analyses including both R&D and educational expenditures, the significant effect of R&D disappears because of the high correlation between the two variables (r=.48), but the general patterns remain the same.

Table 3 Multilevel analyses for the second digital divide with country-level variables

	Use of educationa	l software at home		Internet literacy		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Effects on the intercept						
Intercept	.095 (.087)	.095 (.087)	.095 (.083)	019 (.043)	019 (.043)	019 (.042)
GDP per capita	.703 (.113)**	.684 (.103)**	.615 (.104)**	.183 (.068)**	.156 (.078)*	.155 (.067)*
Composite polity score	.117 (.115)	.103 (.114)	123 (.191)	.039 (.091)	.020 (.090)	036 (.125)
R&D as % of GDP		.025 (.095)			.035 (.035)	
Secondary educational expenditures as % of GDP			.612 (.250)*			.193 (.127)
Effects on the family SES slope						
Intercept	.815 (.027)**	.815 (.025)**	.815 (.025)**	.341 (.012)**	.341 (.011)**	.341 (.012)**
GDP per capita	193 (.041)**	139 (.041)**	164 (.036)**	138 (.022)**	112 (.023)**	135 (.024)**
Composite polity score	022 (.035)	.017 (.045)	.058 (.050)	033 (.035)	015 (.026)	026 (.035)
R&D as % of GDP		071 (.029)*			033 (.009)**	
Secondary educational expenditures as $\%$ of GDP			206 (.058)**			017 (.033)
Variance components						
Between-country intercept variance	.395**	.394**	.349**	.097**	.096**	.093**
Between-country family SES variance	.036**	.032**	.031**	.007**	.006**	.007**
Within-country variance				.810	.810	.810
Log-likelihood	-5,54,259	-5,54,265	-5,54,259	-5,23,894	-5,23,890	-5,23,892
N _{Individual-level}	391,261	391,261	391,261	398,681	398,681	398,681

Note Number of countries = 55. Robust standard errors are in parentheses. All coefficients are adjusted by multiple imputations for missing cases in the control variables (m=10). *Log-likelihood* is from imputed dataset m=1. All models include individual-level control variables (gender, immigration status, foreign language use at home, and family structure). Family SES is group mean centered. All country-level variables are natural log transformed and grand mean centered **p < .01, *p < .05, *p < .1 (2-tailed)

	Use of educational software at home		Internet literacy	
	Model 1	Model 2	Model 3	Model 4
Effects on the Intercept				
Intercept	.495 (.086)**	.368 (.129)**	.048 (.046)	.059 (.045)
Low-income country ^a	-1.004 (.502)*	-1.120 (.446)*	522 (.268)+	484 (.152)**
Middle-income country ^a	358 (.249)	340 (.387)	.001 (.149)	228 (.117)+
Composite polity score	.066 (.167)	394 (.232)+	048 (.107)	107 (.104)
R&D as % of GDP	108 (.083)		.033 (.036)	
R&D as % of GDP×Low-income country	.474 (.339)		083 (.191)	
R&D as % of GDP×Middle-income country	.339 (.270)		.031 (.131)	
Secondary educational expenditures as % of GDP		.742 (.529)		.069 (.141)
Secondary educational expenditures as % of GDP×Low-income country		346 (.626)		.060 (.273)
Secondary educational expenditures as % of GDP×Middle-income country		.077 (.589)		.404 (.242)+
Effects on the family SES slope				
Intercept	.720 (.048)**	.729 (.042)**	.282 (.011)**	.275 (.013)**
Low-income country ^a	.106 (.051)*	.302 (.109)**	.272 (.082)**	.123 (.043)**
Middle-income country ^a	.093 (.056)+	.124 (.102)	.117 (.025)**	.077 (.032)*
Composite polity score	.001 (.057)	.118 (.063)+	.029 (.023)	.068 (.022)**
R&D as % of GDP	026 (.050)		041 (.008)**	
R&D as % of GDP×Low-income country	198 (.062)**		.065 (.054)	
R&D as % of GDP×Middle-income country	089 (.073)		.031 (.031)	
Secondary educational expenditures as % of GDP		228 (.116)*		145 (.036)**
Secondary educational expenditures as % of GDP×Low-income country		.073 (.135)		.287 (.054)**
Secondary educational expenditures as % of GDP \times Middle-income country		.003 (.120)		.069 (.048)
Variance components				
Between-country intercept variance	.368**	.339**	.086**	.079**
Between-country family SES variance	.029**	.030**	.006**	.005**

 Table 4
 Multilevel analyses for the second digital divide: differential effects by country income group

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Table 4 (continued)

	Use of educationa	al software at home	Internet literacy	
	Model 1	Model 2	Model 3	Model 4
Within-country variance			.810	.810
Log-likelihood	-5,54,287	-5,54,265	-5,23,885	- 5,23,879
N _{Individual-level}	391,261	391,261	398,681	398,681

Note Number of countries = 55. Robust standard errors are in parentheses. All coefficients are adjusted by multiple imputations for missing cases in the control variables (m=10). *Log-likelihood* is from imputed dataset m=1. All models include individual-level control variables (gender, immigration status, foreign language use at home, and family structure). Family SES is group mean centered. R&D as % of GDP and Secondary educational expenditures as % of GDP are natural log transformed and grand mean centered

^aHigh-income country is the reference category

***p* < .01, **p* < .05, +*p* < .1 (2-tailed)

GDP per capita in the intercept and the family SES slope equations are .703 and - .193, respectively. This suggests that national income is associated with an increase in the probability of using educational software and, at the same time, a reduction in the socioeconomic disparity in digital use. For example, a one-standard-deviation increase in family SES increases the probability of using educational software by 13% for low-income countries (e.g., India: GDP per capita is \$3960 in U.S. dollars), compared to only 2% for high-income countries (e.g., Netherlands: GDP per capita is \$44,400 in U.S. dollars). The polity score has no significant effect (p > .1). Together, these findings confirm that national income outweighs political freedom when explaining the digital divide (Robison and Crenshaw 2010).

In Model 2 we find that increasing national investment in R&D does not affect educational software use at home, but reduces the socioeconomic gap in its use. The magnitude of the effect is moderate, with a one-log-unit increase in R&D leading to a 19% decrease in the standardized effect of family SES, which is approximately the difference between Serbia (R&D=.87% of GDP) and Australia (R&D=2.4% of GDP). Model 3 shows that students living in countries with higher secondary education expenditures are more likely to use educational software at home (b=.612, p<.05). More importantly, the negative association between educational expenditures and the digital divide is both statistically significant and substantial in size, with a one-unit-increase in expenditures leading to a 25% decrease in the standardized effect of family SES. To place this in the context of our data, a one-standard-deviation increase in family SES increases the probability of using educational software by 21% for countries with lower educational expenditures (e.g., Thailand, where educational expenditures make up 0.64% of GDP), compared to 15% for countries with higher educational expenditures (e.g., Brazil, 2.51% of GDP).

Models 4, 5, and 6 examine the effects of country-level variables on Internet literacy. In Model 4, we see that a one-standard-deviation increase in family SES increases Internet literacy by .341 standard deviations, holding individual-level variables constant. GDP per capita increases students' Internet literacy (b=.183, p<.05) and reduces the Internet literacy gap (b=-.138, p<.01). The polity score is not associated with Internet literacy or the slope of family SES. Model 5 shows that R&D does not have a significant effect on Internet literacy, but significantly reduces the digital divide in Internet literacy (b=-.033, p<.01). In Model 6, we see that educational expenditures as a percent of GDP do not have a significant relationship with Internet literacy or the second digital divide in Internet literacy.

Overall, the results in Table 3 suggest that national income is negatively associated with the second digital divide for teenage students. Net of economic and political factors, investments in R&D and secondary education are associated with reductions in the second digital divide, though the effects of educational expenditures are limited to the use of educational software at home. However, these general patterns may vary across different levels of national income—a possibility we examine next.

5.2 Differential Effects Between Low-, Middle-, and High-Income Countries

Table 4 reports the differential effects of R&D investment and secondary education expenditures on the second digital divide between low-, middle-, and high-income countries. Based on Hypotheses 5a and 5b discussed earlier, we focus on the interaction effects between the key independent variables and the level of national income on the slope of family SES. We report two notable interaction effects. First, Model 1 shows that the



Fig. 2 Predicted family SES slopes by country income group. *Note* Predicted family SES slopes are calculated from Table 4 (Model 1 in the top left corner; Model 2 in the bottom left; Model 3 in the top right; and Model 4 in the bottom right). The plotted lines represent the association between the variable on the *x*-axis and the slope of family SES for low-income (dashed line), middle-income (dotted line), and high-income countries (solid line). The symbols attached to country acronyms represent the predicted family SES slopes adjusted for between-country variance. Both R&D and secondary educational expenditures, measured as % of GDP, are natural log transformed and centered at the grand mean. 0 is the mean of 55 countries. All coefficients are adjusted by multiple imputations for missing cases in the control variables (m = 10)

magnitude of the effect of family SES on educational software use at home is greater for low-income countries (b=.720+.106) than high-income countries (b=.720). Moreover, R&D as a percent of GDP is negatively associated with the family SES slope, but the relationship is much stronger for low-income countries (b=-.026-.198) than high-income countries (b=-.026). Second, Model 4 suggests that the association between secondary educational expenditures and the family SES slope when predicting Internet literacy is negative for high-income countries (b=-.145, p<.01) and moderately negative for middle-income countries (b=-.145+.069, p<.10), but positive for low-income countries (b=-.145+.287, p<.01). In other words, the higher the national income, the greater the negative association between educational expenditures and the socioeconomic divide in Internet literacy.

To further examine the patterns of these differential effects, we plot the predicted slopes of family SES by national income in Fig. 2. Each graph presents the expected level of the digital divide pertinent to the relationship between family SES and the outcome variables of interest (y-axis), conditional on different national income levels with the change of R&D (x-axis on the top charts) or educational expenditures (x-axis on the bottom charts). Beginning with educational software use at home (the left panel), we find a strong negative relationship between R&D and the SES slope for low- and middle-income countries, but not for high-income countries. This finding suggests that investment in R&D can play an important role in reducing the second digital divide in lower-income countries, but it offers little advantage in high-income countries. We should note that low-income countries' R&D investments as a percent of GDP are smaller than most high-income countries, which leaves a lot of room for R&D growth and hence reduction of the second digital divide for these countries. Conversely, the relatively small effect found in high-income countries suggests there may be a ceiling above which further R&D spending is no longer helpful in reducing digital inequality. We also find a negative association between secondary educational expenditures and the digital divide-a relationship that persists across national income levels. This finding suggests that educational expenditures play a role in reducing the digital divide in software use at home in all countries, regardless of national wealth.

Moving to Internet literacy, we also find notably different effects for SES across countries with different levels of national income. Overall, the negative association between R&D and educational expenditures and levels of the digital divide are stronger in high-income countries. First, increased R&D spending is associated with a decline in the effect of SES among high-income countries, but not in low- or middle-income countries.¹¹ This may be due in part to a lack of Internet access in lower-income countries, which can restrict the role of R&D in bridging the second digital divide in Internet literacy. Second, the negative relationship between educational expenditures and the effect of SES exists only in high-income countries, while the effect actually becomes positive when looking at low-income countries. In other words, increased educational expenditures are associated with a widening digital divide in Internet literacy among poor nations. This counterintuitive finding raises the question: why don't educational expenditures lead to greater equality in digital literacy for students in low-income countries?

We consider several possible answers to this question through a series of supplementary analyses.¹² First, because of the small number of countries, it is possible that the patterns for low-income countries observed in Fig. 2 are sensitive to the categorization scheme. To test the robustness of the findings, we repeat the same analyses in Table 4 and Fig. 2 using an alternative classification of country-level income groups derived from the World Bank (2015c).¹³ The conclusion remains consistent.

¹¹ Trinidad & Tobago and Macao are potential outliers in Fig. 2 with regard to the effect of R&D for highincome nations. Supplementary analyses excluding these two countries show patterns consistent with those reported here.

¹² Results from supplementary analyses are not shown here, but are available from the authors upon request.

¹³ Based on the World Bank, there are 6 lower-middle-income countries, 15 upper-middle-income countries, and 34 high-income countries.

Second, it is possible that the high levels of income inequality in less-developed nations may contribute to the widening digital divide. To account for this possibility, we run supplemental analyses including the Gini index as a covariate. We find increased income inequality widens the digital divide (p < .01), but the size of this effect is reduced and becomes statistically non-significant once controlling for national income. More importantly, the levels of income inequality among low-income countries (e.g., Moldova and Tunisia, whose Gini indices are .39 and .41, respectively) are lower on average than most middle-income countries (e.g., Colombia and Brazil, whose Gini index is .56), which suggests that income inequality itself does not explain the widening digital divide in poor countries.

Finally, we consider the possibility that rates of secondary educational enrollment are associated with the level of digital inequality in Internet literacy.¹⁴ We find that higher enrollment rates are associated with greater inequality among less-developed countries, but this association does not exist in developed countries. Together, the results of these analyses suggest the benefits of increased educational spending are disproportionately enjoyed by socioeconomically advantaged students in low-income countries. Unlike the efforts of governments in affluent countries to promote educational *equity*, educational planning in poor countries may prioritize the needs of students who are already socioeconomically privileged while leaving a large number of less-affluent students behind.

To summarize, our analyses in Table 3 show that national income, R&D investments, and educational expenditures have significant effects on reducing the second digital divide among teenage students, providing support for Hypotheses 1, 3, and 4 as put forth earlier. Table 4 and Fig. 2 further indicate significant differences in the effect of national investments in R&D and educational expenditures in bridging the second digital divide across countries with various income levels. Consistent with previous literature that questions the role of educational expenditures in reducing educational inequalities (Hannum and Buchmann 2005; Juárez and Gayet 2014), our findings indicate that, among less-developed countries, the benefits of increased educational spending may be limited to only the most affluent students. In contrast, increased educational spending in developed countries is more beneficial to less-affluent students (Hypothesis 5a).

6 Discussion and Conclusion

The use of digital technology in education has continued to grow in the past decade, making digital literacy an increasingly important component of success for students. However, despite its growing importance for education, a digital divide in technology use persists worldwide. Based on PISA reports, the disparity in digital access—referred to as the first digital divide—has narrowed in most countries, while the disparity in digital use between students from varying socioeconomic backgrounds remains substantial (OECD 2011, 2015). Findings from the PISA 2009 digital reading assessments for students across 19 countries suggest that SES explains about 14% of the variation in students' digital reading performance, which is equivalent to a gap of over 2 years of schooling (OECD 2011, p. 124). According to PISA 2012 data, low-SES students have weak computer navigation skills and online literacy compared to high-SES students and are less likely to start using

¹⁴ The Gini index data are obtained from the World Income Inequality Database (UNU-WIDER 2008). Secondary education enrollment rates are derived from the World Bank (2015a).

computers for learning in early childhood because their families "may not be aware of how technology can help to raise one's social status (OECD 2015, p. 125)." This socioeconomic disparity in digital use, known as the second digital divide, has been identified in every country where data have been collected (Notten et al. 2009).

Despite the wealth of research on the digital divide, national-level factors that contribute to the second digital divide among students have received limited attention. This is surprising, since scholars have long recognized the need to investigate the role of public policies in the integration of e-learning into schools and education (DiMaggio et al. 2004; Erichsen and Salajan 2014; Natriello 2001). Motivated by this gap in the research as well as findings from previous studies (Norris 2001), we investigate how national income, political freedom, and national investments in R&D and secondary education are associated with the second digital divide among 15-year-old students in 55 countries.

Our analyses reveal several key findings. First, we find national income to be a powerful predictor of the second digital divide among teenage students. Additionally, national investments in R&D and secondary education are negatively associated with the second digital divide. The size of the relationships for these measures are modest, but they remain statistically significant even after controlling for national income and individual-level background characteristics. Given these findings, we surmise that targeted investments in research, innovation, and education aimed at enhancing digital learning opportunities for all students could potentially reduce digital inequality. Policymakers interested in reducing digital inequality may want to consider this finding when constructing policies to address the digital divide.

Equally important, we find that the economic standing of countries shapes how different national investments may influence digital inequality among youths. For example, R&D spending reduces the second digital divide in educational software use at home, but only in less-developed countries, suggesting there may be an opportunity to reduce the digital divide for these countries since they have the greatest room to expand their investments in R&D (see Table 6 in the "Appendix" for examples). Moreover, increased R&D spending and educational expenditures are associated with reducing the Internet literacy gap among high-income countries, but not in low- or middle-income countries. In fact, and perhaps surprisingly, increased expenditures on education in low-income countries lead to a widening Internet literacy gap between lower-SES and higher-SES students. This may be attributable to the complex interaction of several socio-economic factors such as lack of social mobility, weak labor markets, and widespread poverty in less-affluent countries. We find some evidence to support this possibility in our data. For example, among the low-income countries in our sample, Moldova has the highest level of educational expenditures, but its strikingly poor economic conditions have further exacerbated the hardships of socioeconomically disadvantaged students (Worden 2014).

Despite these significant findings, we acknowledge several shortcomings in this study and recommend future directions for research. First, since the PISA survey focuses overwhelmingly on high-income countries—a common problem with international datasets (Chiu 2010; Park and Kyei 2011)— the number of less-developed countries is limited in our analysis. Future efforts to collect international comparative data from a more diverse array of countries will help to reduce this problem. Future scholars should pay special attention to data from the developing world, as our study indicates the importance of looking at the differences in effects between countries of different income levels. Second, we note our inability to ascertain the causal relationship between educational expenditures and the level of the second digital divide.¹⁵ To establish that connection, future research may draw from longitudinal data to examine the change in expenditures and the level of digital inequality across time. Third, our multilevel analyses allow family SES to vary randomly across country-level clusters, but overlook the random effects of other individual-level controls. Future research should consider using two-step approaches that contain a flexible random-effects structure which may yield more precise estimates (Heisig et al. 2017).

Finally, future qualitative and quantitative research should explore specific projects, policies, or practices that directly or indirectly promote digital literacy—especially among economically disadvantaged students. This includes studying the influence of other nationallevel indicators from sources outside of the PISA dataset, such as the Human Development Index by the United Nations Development Programme, social welfare expenditures from the World Bank's World Development Indicators, and other educational indices created by the World Bank's Education Statistics, to name a few possibilities. Since digital technology appears likely to be a dominant force in society for the foreseeable future—affecting earnings and other social outcomes—ensuring the next generation is digitally literate should be a priority for countries seeking to compete in the global economy. So long as a high level of inequality in digital use persists, social scientists must continue to seek out solutions by exploring various local and national investments which governments can make to help reduce the second digital divide.

Acknowledgements The authors would like to thank Brian Powell, Michael Wallace, Jeremy Pais, Mary Fischer, David Weakliem, Thung-Hong Lin, and several anonymous reviewers for valuable comments on previous versions of this paper.

Appendix

See Tables 5 and 6 and Fig. 3.

¹⁵ While educational expenditures have a clear and direct relationship to students, countries may distribute their educational resources in ways that are unrelated to digital technology use. The distribution of educational investments within a country could also be biased by social status, with newer technologies going only to schools in the most affluent areas. Bearing these possibilities in mind, we examine whether or not these investments, when used appropriately, may serve as tools to reduce the second digital divide.

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Country	ntry Sample size Use of educa- tional software at home		Internet	literacy	Family SES		
		Mean	SD	Mean	SD	Mean	SD
Argentina (AR)	4774	.40	.49	27	.97	19	1.02
Australia (AU)	14,251	.70	.46	01	.86	.60	.66
Austria (AT)	6590	.49	.50	.13	.87	.40	.72
Belgium (BE)	8501	.64	.48	20	.81	.51	.80
Brazil (BR)	20,127	.24	.43	37	1.12	70	1.05
Bulgaria (BG)	4507	.62	.48	.45	1.22	.23	.86
Chile (CL)	5669	.37	.48	.00	.97	11	1.01
Colombia (CO)	7921	.37	.48	07	.96	55	1.08
Costa Rica (CR)	4578	.41	.49	46	.96	48	1.14
Czech (CZ)	6064	.64	.48	.66	.88	.34	.64
Denmark (DK)	5924	.73	.44	.21	.83	.44	.81
Estonia (EE)	4727	.69	.46	.61	.86	.48	.69
Finland (FI)	5810	.35	.48	.02	.81	.68	.68
France (FR)	4298	.39	.49	02	.84	.23	.73
Georgia (GE)	4646	.27	.44	03	1.14	.10	.85
Germany (DE)	4979	.57	.49	.23	.85	.48	.79
Greece (GR)	4969	.42	.49	.08	1.02	.35	.86
Hong Kong (HK)	4837	.57	.49	.58	.84	38	.88
Hungary (HU)	4605	.47	.50	.53	.95	.19	.82
India (IN)	4826	.17	.38	90	1.27	-1.11	.96
Indonesia (ID)	5136	.16	.36	77	.97	-1.00	.95
Ireland (IE)	3937	.57	.49	35	.85	.38	.74
Israel (IL)	5761	.54	.50	.26	.96	.32	.77
Italy (IT)	30,905	.54	.50	.11	1.00	.24	.85
Japan (JP)	6088	.16	.36	30	.95	.32	.63
Jordan (JO)	6486	.53	.50	32	1.14	10	.89
Korea (KR)	4989	.60	.49	.21	.85	.21	.71
Latvia (LV)	4502	.70	.46	.53	.89	.29	.75
Lithuania (LT)	4528	.61	.49	.71	.95	.30	.84
Macao (MO)	5952	.62	.49	.13	.85	28	.75
Malaysia (MY)	4999	.56	.50	40	1.00	10	.77
Mauritius (MU)	4654	.59	.49	16	1.09	25	.87
Mexico (MX)	38,250	.32	.47	14	.91	67	1.11
Moldova (MD)	5194	.35	.48	.12	1.25	16	.85
Netherlands (NL)	4760	.70	.46	01	.82	.60	.74
New Zealand (NZ)	4643	.63	.48	09	.85	.41	.68
Norway (NO)	4660	.68	.47	.27	.83	.74	.64
Panama (PA)	3969	.31	.46	17	1.14	33	1.11
Peru (PE)	5985	.31	.46	27	1.02	80	1.07
Poland (PL)	4917	.74	.44	.71	.94	.14	.79
Portugal (PT)	6298	.65	.48	.24	.87	.07	1.01
Serbia (RS)	5523	.51	.50	06	1.08	.39	.83

 Table 5
 Sample size and descriptive statistics for key individual-level variables in 55 countries

Country	Sample size	Use of educa- tional software at home		Internet literacy		Family SES	
		Mean	SD	Mean	SD	Mean	SD
Shanghai (CN)	5115	.40	.49	06	.89	09	.91
Singapore (SG)	5283	.64	.48	.27	.95	04	.70
Slovakia (SK)	4555	.60	.49	.18	.97	.25	.73
Slovenia (SI)	6155	.72	.45	.30	.92	.28	.76
Spain (ES)	25,887	.52	.50	.00	.87	.11	.91
Sweden (SE)	4567	.58	.49	.13	.84	.62	.70
Switzerland (CH)	11,812	.51	.50	.06	.84	.35	.74
Thailand (TH)	6225	.32	.47	28	1.04	69	1.09
Trinidad & Tobago (TT)	4778	.63	.48	24	1.00	16	.82
Tunisia (TN)	4955	.32	.47	55	1.15	74	1.13
United Kingdom (GB)	12,179	.70	.46	.10	.89	.48	.68
United States (US)	5233	.60	.49	.00	.96	.46	.80
Uruguay (UY)	5957	.45	.50	01	1.01	32	1.07

Table 5 (continued)

	GDP per capita	Composite polity score	R&D as % of GDP	Secondary educational expenditures as % of GDP
Low-income countries				
Moldova (MD)	3.54	8.00	.53	3.63
India (IN)	3.96	9.00	.82	1.12
Georgia (GE)	5.46	6.00	.18	1.08
Indonesia (ID)	7.82	8.00	.08	.90
Peru (PE)	8.93	9.00	.16	1.05
Tunisia (TN)	9.96	-4.00	.71	2.97
Jordan (JO)	10.88	-3.00	.43	1.77
Thailand (TH)	12.26	4.00	.25	.64
Mean	7.85	4.63	.39	1.65
Middle-income countries				
Shanghai (CN)	10.13	-7.00	1.68	.71
Colombia (CO)	10.26	7.00	.21	1.66
Serbia (RS)	11.81	8.00	.87	1.12
Costa Rica (CR)	11.82	10.00	.54	1.36
Brazil (BR)	13.09	8.00	1.12	2.51
Mexico (MX)	13.91	8.00	.43	1.58
Panama (PA)	14.10	9.00	.14	1.10
Mauritius (MU)	14.54	10.00	.37	1.51
Argentina (AR)	14.60	8.00	.48	1.99
Bulgaria (BG)	14.88	9.00	.51	1.80
Uruguay (UY)	15.39	10.00	.42	1.04
Chile (CL)	16.23	10.00	.35	1.49
Latvia (LV)	17.04	8.00	.45	2.27
Lithuania (LT)	18.28	10.00	.83	2.95
Poland (PL)	19.15	10.00	.67	1.85
Malaysia (MY)	19.33	6.00	1.01	1.96
Hungary (HU)	20.87	10.00	1.14	2.04
Mean	15.02	7.88	.66	1.70
High-income countries				
Estonia (EE)	20.21	9.00	1.40	2.40
Slovakia (SK)	23.18	10.00	.47	1.90
Portugal (PT)	26.22	10.00	1.58	2.50
Czech (CZ)	27.02	8.00	1.30	1.94
Slovenia (SI)	27.52	10.00	1.82	2.65
Israel (IL)	27.58	10.00	4.15	1.48
Korea (KR)	28.39	8.00	3.29	1.78
Trinidad & Tobago (TT)	29.12	10.00	.06	1.62
Greece (GR)	30.44	10.00	.63	1.35
New Zealand (NZ)	30.50	10.00	1.26	2.38
Japan (JP)	31.86	10.00	3.36	1.29
Spain (ES)	32.81	10.00	1.35	1.83
Italy (IT)	34.17	10.00	1.22	1.95

 Table 6
 Country-level variables: 55 countries

	GDP per capita	Composite polity score	R&D as % of GDP	Secondary educational expenditures as % of GDP
France (FR)	34.81	9.00	2.21	2.60
United Kingdom (GB)	36.37	10.00	1.75	2.60
Germany (DE)	37.12	10.00	2.73	2.26
Finland (FI)	37.55	10.00	3.75	2.76
Belgium (BE)	37.64	8.00	1.97	2.77
Denmark (DK)	39.62	10.00	3.07	2.86
Sweden (SE)	39.67	10.00	3.42	2.52
Australia (AU)	40.21	10.00	2.40	1.92
Austria (AT)	40.63	10.00	2.61	2.70
Ireland (IE)	41.88	10.00	1.63	2.09
Hong Kong (HK)	43.94	-7.00	.77	1.21
Netherlands (NL)	44.40	10.00	1.69	2.23
United States (US)	47.00	10.00	2.82	1.97
Switzerland (CH)	49.92	10.00	2.73	2.10
Norway (NO)	56.19	10.00	1.72	2.54
Singapore (SG)	61.60	-2.00	2.16	.75
Macao (MO)	76.85	-7.00	.05	.92
Mean	37.81	8.20	1.98	2.06

Table 6 (continued)

Note GDP per capita is in thousands of 2009 purchasing power parity dollars. The classification of income groups is based on the ITU (2011). Countries within groups are sorted by GDP per capita. All of the country-level data are from 2009. For countries with missing data on R&D as % of GDP in 2009, we use the closest available data year: Australia (2008), Georgia (2005), Jordan (2008), Mauritius (2005), Peru (2004), and Switzerland (2008). For countries with missing data on secondary educational expenditures as % of GDP in 2009, we use the closest available data year: Costa Rica (2004), Georgia (2008), Greece (2005), Japan (2008), Macao (2000), Panama (2007), Shanghai (1999), Slovenia (2003), Tunisia (2008), and Uruguay (2006)



Fig.3 Effects of R&D and secondary educational expenditures on family SES slopes by country income group: digital use for schoolwork at home *vs.* use of educational software at home^a. *Note* Predicted family SES slopes are based on the same model specifications in Table 4 but limited to only 36 countries with valid data for the two dependent variables. ^a Standardized composite measure based on five items: (1) browsing the Internet for schoolwork, (2) using e-mail to communicate with other students about schoolwork, (3) using e-mail to communicate with teachers and for submission of schoolwork, (4) using material from the school's website, and (5) checking the school's website for announcements

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