Social Research Institute

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Quantitative Social Science

Working Paper No. 21-05

February 2021

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Abstract

In 2018, about one in three (33%) 15-year-olds, on average across 52 high- and middle-income countries, played videogames every day or almost every day. Among boys, that proportion was close to one in two (49%). Many popular videogames among teenagers encourage inductive discovery as an effective problem-solving strategy. Written instructions seldom need to be read. By contrast, gaming often involves early information foraging and expansive exploration behaviors. In this paper, we use data from the 2018 wave of the Programme for International Student Assessment to explore whether students who regularly play video-games (gamers) adopt behaviors that are typical of gaming while they complete a computer-based assessment of science. The assessment included interactive items designed to identify procedural science knowledge as well as static items designed to identify science content knowledge. We find that gamers do not differ from other students in science content knowledge and in reading fluency, a measure of how fast they read. Compared to other students, gamers spend less time reading instructions and display more active exploration behaviors in the assessment on items that include simulation tools. We examine differences in associations by country and by sex. We discuss the implications for education practice and for the design of computer-based assessments.

Keywords: Videogames; science problem solving, time to first action, exploration, computer-based assessment.

JEL Codes: I20; I24; I26

Acknowledgements: Francesca Borgonovi recognises support from the British Academy through its Global Professorship scheme. The authors would like to thank participants in seminars at UCL and the OECD.

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1. Introduction

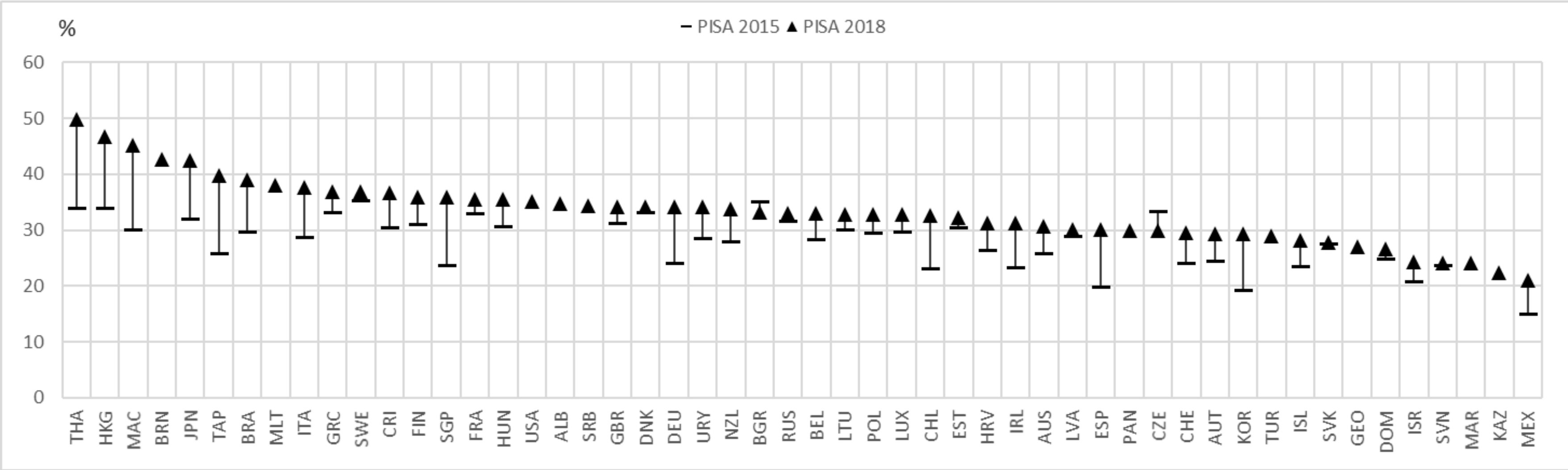
Play is a ubiquitous feature of life: even young plants play (Mancuso, 2018). Play is, in essence, a form of learning through experimentation (Granic, Lobel, & Engels, 2013). By playing, the young engage in a low-stake activity that allows them to learn the social, emotional and physical consequences of their actions (Erikson, 1977; Pellegrini, 2009). In some games, rules and guidelines are spelled out at the onset, and the gaming process is designed to stimulate both the ability to follow rules and an understanding of the consequences of rule breaking. In others, discovering the rules governing a game is a key step of the gaming process (Pellegrini, 2009). This is especially true in the case of videogames, i.e. interactive games operated by computer circuitry that allow individuals to engage in simulated worlds (Shaffer, Squire, Halverson, & Gee, 2005).

When gamers approach a videogame for the first time they are rarely confronted with instructions; rather, they are expected to understand the rules by playing. Videogames therefore allow individuals, irrespective of their attitudes towards formal education and learning, to practice problem solving and to exercise a scientific mode of inquiry (Steinkuehler & Duncan, 2008). Gamers engage in scientific reasoning during gaming sessions and while they discuss about videogames with other gamers (Steinkuehler & Duncan, 2008).

Gaming is one of the most popular activities among teenagers worldwide. Figure 1 illustrates the percentage of 15-year-olds who reported playing videogames daily in 2018, across 52 PISA samples, and the corresponding percentage in 2015 (where available). Results indicate that the percentage of students who reported playing videogames daily increased markedly between 2015 and 2018 in most education systems with available data: in some, including Chile, Germany, Hong Kong, Japan, Korea, Macao (China), Singapore, Spain, Chinese Taipei and

Thailand, it increased by 10 percentage points or more. In all countries with available data in 2018 at least one in five 15-year-olds played daily in 2018.

Figure 1
Trends in the percentage of 15-year-old students who play videogames daily between 2015 and 2018, by country



Note: Countries/economies are ranked in descending order of the 2018 proportion. Only 52 countries and economies with data about video-gaming frequency in PISA 2018 are shown. PISA 2015 data are not available for Brunei, United States, Albania, Serbia, Panama, Georgia, Morocco and Kazakhstan.
Source: PISA 2015 and 2018 databases.

Previous work examined the effect of videogaming on self-reported general problem solving skills (Adachi & Willoughby, 2013) and the effects of being a proficient, rather than a novel player, on the set of problem solving strategies individuals adopted in the gaming situation (VanDeventer and White, 2002). In this work we use data from the 2018 edition of the Programme for International Student Assessment (PISA) to provide evidence from large, representative samples of adolescents, on differences in the problem-solving behaviors adopted when solving science problems between teenagers who play videogames daily and teenagers who play videogames less frequently (if at all). The contribution of our work is threefold. First, we identify if gamers approach scientific problem-solving differently from non-gamers. Second, we assess if gamers differences in the approach taken to solve problems explain differences between gamers and non-gamers in their science achievement. Finally, we examine gender differences in gaming and if the set of behavioral tendencies in the approach to science problems that are associated with gaming differ across genders, and what implications these may have for gender differences in science achievement.

Our target situation involves 8 science tasks included in an academic test of science, which are characterized by their “interactive nature”, i.e. by the fact that the task environment dynamically responds to the test-takers’ actions, e.g. by revealing new data that were previously unavailable. These tasks are meant to simulate the process of doing science – of designing experiments, interpreting results, and making predictions informed by data and prior knowledge. The interactive nature of the tests also incorporates many of the features that are typical of videogames. We find that students who play games daily are more likely than other students to start exploring the problem space very rapidly - to the point of not having the time to read instructions – and to seek more information from the system than what would be strictly necessary to reach a solution. Other things being equal, we do not find differences between gamers and non-gamers in the likelihood of success on interactive science tasks, measured by their probability of solving the tasks correctly. We find that boys are considerably more likely to play video games than girls, to start exploring the problem space faster than girls and to engage greater information harvesting than girls. Among gamers, gender differences in how fast students start exploring the problem space are smaller, gender differences in information harvesting are larger and boys outperform girls with similar background characteristics in interactive science tasks.

2. Theory and Study Aims

The literature has examined at length the effects of gaming on the academic achievement and mental well-being of teenagers (Gentile, 2009; McDool, Powell, Roberts, & Taylor, 2020; Przybylski, 2014; Przybylski & Weinstein, 2017; Smyth, 2007; Weis & Cerankosky, 2010). Such literature can be divided in studies that examine the indirect displacement effects of videogaming and studies that examine the direct effects of videogaming.

Proponents of the displacement hypothesis predict that videogaming will have negative effects on achievement because time spent videogaming is time not spent on activities that are strongly and positively associated with academic achievement (Weis & Cerankosky, 2010). Results in this literature are inherently relative, because they depend on the selection of what alternative uses of time are selected and their expected achievement benefits but also, on the extent to which displacement occurs. While self-study and doing homework may be strongly associated with academic achievement, it is possible that teenagers who play videogaming would not be doing such activities if they were prevented from playing videogames.

The literature on the direct effects of gaming is more diverse. On the one side, researchers have examined the negative effects of gaming on attention difficulties (Gentile et al., 2011; Swing, Gentile, Anderson, & Walsh, 2010), violence and aggressiveness (Gentile, Lynch, Linder, & Walsh, 2004), psychosocial health (Przybylski 2014; Przybylski & Weinstein, 2017), and general lack of perseverance and motivation (Cummings & Vandewater, 2007; Ferguson, 2010; Swing et al., 2010). On the other side, researchers have identified a positive effect of gaming on the acquisition of skills. For example, videogaming has been shown to promote the development of visual spatial skills (De Lisi & Wolford, 2010; Gagnon, 1985; Griffith, Voloschin, Gibb, & Bailey, 1983; Spence & Feng, 2010; Subrahmanyam & Greenfield, 1994) which are important in themselves and are pre-cursor for the development of skills in mathematics. In particular, action videogame players display superior top-down visual attention control (Cain, Prinzmetal, Shimamura, & Landau, 2014; Wu & Spence, 2013), response speed and accuracy (Cain et al., 2014; Castel, Pratt, & Drummond, 2005; Hubert-Wallander, Green, & Bavelier, 2011; Wu & Spence, 2013), ability to localize targets among distractors (Chisholm & Kingstone, 2012; Greenfield, et al., 1994; Hubert-Wallander et al., 2011; Wu & Spence, 2013), ability to track multiple objects simultaneously (Dye & Bavelier, 2010; Green & Bavelier, 2006), and ability to switch tasks (Dye & Bavelier, 2010; Green & Bavelier, 2003; Pohl et al., 2014).

Although this last line of research shows that gamers outperform non-gamers on some tasks, there is much debate regarding whether the training benefits of videogames are task-specific or task general. Lack of transferability of skills across tasks and lack of applicability of skills developed through gaming to educational settings would render the learning gains of gaming inconsequential for education.

The learning to learn theory proposes that playing videogames could lead to the development of transferable skills that are important in educational settings such as improved attentional control, pattern recognition, and resource allocation (Bavelier, Green, Pouget, &

Schrater, 2012; Feng & Spence, 2018; Green & Bavelier, 2012; Weinstein & Lejoyeux, 2015). Work has also identified an association between videogaming and self-reported persistence while engaging in problem solving (Adachi & Willoughby, 2013) and between videogaming and performance-based measures of persistence (Ventura, Shute, & Zhao, 2013).

By contrast, the common demands theory maintains that any post-training benefits arising from gaming will be task-specific, and that performance improvements will only be observed in tasks that share very similar cognitive demands to those involved in the training task (i.e. the game) (Azizi, Abel, & Stainer, 2018; Azizi & Arbai, 2017; Oei & Patterson, 2014, Oei & Patterson, 2015; Sala, Tatlidil, & Gobet, 2018; Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008; Dahlin, Nyberg, Bäckman, & Neely, 2008).

Empirical research on the learning effects of videogaming indicates that different games require players to practice different sets of skills, although most games encourage, to a larger or smaller degree, inductive discovery as an effective gaming strategy. Inductive discovery describes the cognitive process of formulating hypotheses about rules governing a situation, identifying patterns and implementing strategies in response to stimuli received. Players practice inductive discovery when they use input received during a gaming session to develop an understanding of how the game works. Inductive discovery means that gamers typically discover gaming strategies through a process of trial and error: by playing multiple sessions and through a wide-ranging exploration of the gaming environment. Because gamers can play a potentially infinite number of rounds, when they encounter a new game, they typically over-explore the problem space, especially in the earlier rounds of the game. Making mistakes and exploring the game in its entirely in fact allows players to simulate alternative scenarios and test hypotheses about the effectiveness of different gaming strategies (Greenfield et al., 1994). These features apply both to games in which the player needs to adapt his or her behavior to the behavior of others (in multiplayer games) and to situations that evolve based on algorithms built in the game (like in solo card games or one-player computer games).

In line with the learning to learn theory, we hypothesize that gamers will approach problem situations in which inductive discovery is a possible strategy similarly to the way in which they would approach a game, even when such problem situations arise outside of a videogame. In particular, we expect that in a computer-based assessment of science which includes simulation tools, children who play videogames regularly will be less likely to devote time to read instructions and will interact with the computer situation to a higher degree than what would be strictly necessary to solve the problem at hand. We also explore whether behavioral tendencies of gamers and other students will differ depending on the characteristics of students. Behavioral and neural evidence in fact indicates that the outcomes arising from gaming can differ across individuals (Boot, Kramer, Simons, Fabiani, & Gratton, 2008): individual characteristics and prior gaming experience explain some of the observed variability in skill acquisition, performance improvement, and skill transfer rates observed as a result of gaming (Spence et al., 2009; Wu et al., 2012).

3. Materials and Methods

3.1. The Programme for International Student Assessment

PISA is an international large-scale assessment that has been administered to samples of 15-year-old students every three years since 2000 and, since 2015, is administered on computers. Computer delivery allows to trace how students interact with the test questions and identify indicators that describe problem-solving strategies; it also allows test developers to develop tasks that evolve dynamically, in reaction to test-takers' actions. Such interactive tasks lend themselves for example to assessing the ability of students to conduct scientific inquiry in a virtual laboratory. PISA involves large-representative samples of students from countries that vary widely in cultural, linguistic and social background, pedagogical approaches used in schools and share of teenagers who regularly play videogames.

3.2. Participants

Our data come from the 2018 edition of PISA. All cases used in our analyses were extracted from the public-use files for the PISA 2018 computer-based test, which can be downloaded from: http://www.oecd.org/pisa/data/ . In 2018, PISA participants were selected from the population of 15-year-old students in participating countries according to a two-stage random sampling procedure, so that weighted samples are representative of students who are enrolled in grade 7 or above and are between 15 years and 3 months and 16 years and 2 months at the time of the assessment administration (generally referred to as 15-year-olds in this work). In the first stage, a stratified sample of schools was drawn. In the second stage, students were selected at random in each sampled school. Finally, on the day of the test, students are assigned to one of many distinct, but partially overlapping test forms. We focus on those students that were assigned to a test form containing interactive science items (see section "instruments", below): this includes about 26% of the PISA 2018 sample, when the major focus of the assessment was reading, and only a reduced sample within each school was assigned to test forms including science items.

While more than 70 national samples exist for 2018, our study is based on the subset of countries that administered the optional Information and Communication Technology (ICT) questionnaire to students. The ICT questionnaire is a 10-15 minutes questionnaire designed to identify technology availability and use among 15-year-olds. In total, 377 635 students were included in the PISA sample for these countries in 2018. Furthermore, for regression analyses which relate video-game practice with test-taking behaviors, our sample is restricted to the subset of students who were assigned one of the test forms containing interactive science questions. Since PISA assigns students to test forms at random, this subset is representative of the wider population of 15-year-old students (excluding a small percentage of students with special education needs, who were either excluded from PISA samples because no adaptation was available for them, or assigned to a shorter test and questionnaire, not containing the items and questions used in our analysis). We excluded students from the samples used for our analysis if information was missing on one or more variables used in the analysis (listwise deletion).

3.3. Instruments

We focus on three units (groups of items built around a common set of resources available to students) which were included in the science test in PISA in 2018. These three units reflect the affordances of computer-based tests for the assessment of science. A common feature of these units is their "interactive" nature: among the resources provided to students is a simple simulation device, which students can use by manipulating inputs and running multiple simulations. In most items included in these units, students must interact with the simulation tool to generate data required to successfully answer the assessment task (we exclude from our analysis the few tasks, within these units, where the simulation tool is not available; these non-interactive tasks were presented either at the beginning or at the end of some of the units).

Although all items used in this study must remain confidential, because they continue to be used in operational PISA tests, an illustrative unit for this type of test task was released by the OECD and can serve to illustrate the main features of these units. Unit *RUNNING IN HOT WEATHER* can be found at http://www.oecd.org/pisa/PISA2015Questions/platform/index.html?user=&domain=SCI&unit=S623-RunningInHotWeather&lang=eng-ZZZ.

In the simplest items in these units (exemplified by Question 1 of unit *RUNNING IN HOT WEATHER*), students are guided in their exploration and must follow instructions; typically, a single run of the simulation tool (with the adequate settings) is sufficient to answer the question. In more difficult items (such as Question 2 in the same sample unit), students must figure out by themselves which simulations to run, and must run multiple simulations to get the right answer (i.e. they must design and carry out their own scientific inquiry). In some items (see Questions 3, 4 and 5 in the sample unit), students also had to type an answer in an open-entry field.

All students were familiarized with the simulation tool in the orientation section to the science test, before the proper test began, and through a "dummy item" at the beginning of these units (called introduction); in this dummy item, they had to run one simulation before they could proceed to the proper question items. This served to confirm that all students had located the controls for running simulations (data from the introductory item are not used).

3.4. Procedure

On the day of the test, students who were selected to take part in the PISA study sat in a dedicated room fitted with computers under the supervision of an invigilator. Participants were first administered a timed two-hour test and then a questionnaire designed to take around 30 minutes for completion. Participants were typically selected from different classes and grades. Students first familiarized themselves with the PISA computer platform. They were told that the test would last for two hours, with a break after the first hour of testing, and that the test would be followed by a questionnaire. They were also given an opportunity to practice all response formats and to explore the (simple) navigation tools embedded in the test platform before starting the test. Students who were assigned to the science section of the test were also introduced to the simulation tool, and could practice running simulations before starting the test. After the two-hour test, students were asked to complete a questionnaire (whose total duration never exceeded one hour).

Students' response data (e.g. the selected option, in a multiple-choice question), a limited set of "generic" process data including time-on-task, time-to-first-action, the overall number of actions, and a number of task-specific pre-programmed features (e.g. the number of simulation runs in interactive items) were captured by the computer platform.

3.5. Variable description

3.5.1. Outcome variables

We use two indicators to identify students' problem-solving strategies: time to first action and number of simulation trials. The time-to-first-action indicator represents the time span between the moment students' first view a test question (start) and the moment in which they take the first action that involves a (meaningful) interaction with the computer platform (action_x). This lag can be taken as a proxy of how much time students spend reading instructions before they interact with the problem situation or with answer fields.

The number-of-trials indicator is available only in interactive items that include a simulation tool; it represents the number of simulation runs performed by the student and can be considered a proxy of the amount of information harvesting.

Since the time to first action depends on the length of the prompt and the number of simulation runs depends on features of individual items, in order to compare the indicators across different items, we use norm-referenced scores (percentile scores). For each indicator we use percentile values based on the distribution of the underlying indicator in each country, to net out differences across countries in reading load due to, for example, language characteristics. These analyses allow to compare the behavior of gamers and non-gamers within countries but not across countries. The percentile transformation forces an approximately uniform distribution on the timing and actions data, while maintaining any mass points that exist in the underlying variable (equal values in the underlying variable are mapped the same, middle, percentile value); it also reduces the influence of any outlier on the analysis.

We also develop a measure of procedural science performance – a percent-correct score based on the same interactive items used for the behavioral analysis – to examine whether differences between gamers and non-gamers in *how* they solve problems are also mirrored in similar differences in *whether* they solve these problems successfully. To the extent that inductive discovery is an appropriate procedure for the scientific problems presented, we expect a similar relationship with this performance measure as observed on behavioral indicators.

3.5.2. Key independent variable

Our key independent variable is a dichotomous indicator of whether students play videogames daily (value 1) or not (value 0). In the ICT familiarity questionnaire students are asked to report how often they use digital devices outside of school to play one-player games, collaborative online games and online games via social networks. Students could report playing each of such games 'never or hardly ever'; 'once or twice a month'; 'once or twice a week'; 'almost every day'; and 'every day'. We construct a dichotomous indicator (with values 0 and 1), where a value of one is assigned to students who report playing any of the three types of games daily or playing at least two of the three games almost every day.

3.5.3. Control variables

Students' sex was reported in the student tracking form completed by school administrators as well as by students in the questionnaire and takes value 1 among girls and 2 among boys. Students' reading fluency was introduced to control for how fast students read. The measure was derived using the total time students took to read (and understand) 22 sentences (reading fluency items). Since virtually all students correctly identified the meaningless sentences among the 22, accuracy was not considered. For each student we assign a within country percentile distribution of total completion time with the fastest student being assigned a value of 100 and the slowest student being assigned a value of 0.

We introduce a percent-correct score on traditional science items, measuring students' knowledge of science facts and theories (content knowledge) as a control measuring science knowledge. The variable is used to confirm that the difference between gamers and non-gamers in procedural science achievement is not confounded by differences in more traditional science knowledge.

Finally, we control for students' socio-economic condition through the PISA index of economic, social and cultural status (ESCS), an aggregate indicator reflecting students' household resources, parental educational attainment and occupational status (Avvisati, 2020) and for students' experience with computers through the age at which students reported having first used a digital device. Students could report never having used a digital device, or having used a digital device for the first time when they were 3 years old or younger, when they were between the age of 3 and 6, when they were between the age of 7 and 9, when they were between the age of 10 and 12 or when they were 13 years old or older.

3.6. Analysis

We first illustrate, using a sample item, differences between gamers and non-gamers in how much information harvesting the two groups engaged in and the amount of time elapsed between being presented the item and the moment individuals started engaging with the item. We then develop regression analyses aimed at identifying the association between videogaming and time to first action and information harvesting across different items. In Table 3 we report average associations across countries, based on separate country-specific regressions. Average coefficients are obtained as an equally-weighted average of country-level coefficients (each country contributes equally irrespective of size of the sample or size of the underlying target population); standard errors for these averages are obtained under the assumption of independent sampling errors across countries. In Figure 2 we present country specific results for the two parameters of interest - difference in time to first action and number of simulation trials.

We also report differences in the behaviors adopted by gamers and non-gamers and in achievement on procedural science items. In addition to reporting the raw differences (model 1), we develop models that adjust for background characteristics (model 2).

Finally, we develop analyses to identify if the association between videogaming and behaviors and between gaming and achievement differs by gender. We do so by introducing interaction terms between the dichotomous videogaming variable and whether the respondent is a boy or a girl (model 3).

4. Results

4.1. Descriptive evidence

Table 1 illustrates descriptive statistics for all variables used in the analysis. Gamers and non-gamers do not differ, on average across countries, in terms of reading fluency, science content knowledge and socio-economic status. By contrast, gamers appear to have a larger number of years spent using digital devices, have lower reading achievement and are more likely to be boys. In fact, the lower reading achievement of daily gamers reflects the gender distribution of gamers and the fact that boys are more likely to lag behind in reading than girls (Buchmann, DiPrete, & McDaniel, 2008; DiPrete & Buchmann, 2013).

Table 1

Descriptive statistics (international average)

Variables	Number of observations	Mean		Standard Deviation		Mean among non-gamers		Mean among gamers		Mean difference (gamers vs. non-gamers)	
Behaviour and success in simulation-based science items											
Sample item											
Number of simulation trials	43191	3.3	(0.02)	3.2	(0.03)	3.2	(0.02)	3.5	(0.03)	0.4	(0.04)
Time to first action (sec)	42832	21.4	(0.10)	17.9	(0.15)	22.4	(0.13)	19.3	(0.16)	-3.0	(0.21)
Percent correct (%)	43037	23.1	(0.23)			23.7	(0.28)	21.7	(0.38)	-2.0	(0.47)
All Target items											
Information harvesting (percentile)	97206	51.6	(0.08)	20.7	(0.05)	51.1	(0.10)	52.5	(0.13)	1.4	(0.16)
Time to first action (percentile)	97206	50.7	(0.08)	19.9	(0.05)	51.8	(0.10)	48.5	(0.13)	-3.3	(0.16)
Percent correct (%)	97206	44.3	(0.13)			44.0	(0.15)	44.8	(0.20)	0.8	(0.24)
Sample characteristics											
Boy (%)	97206	49.8	(0.19)			38.0	(0.22)	73.7	(0.28)	35.7	(0.36)
Index of economic, social and cultural status (ESCS)	97206	-0.2	(0.00)	0.9	(0.00)	-0.2	(0.01)	-0.2	(0.01)	0.0	(0.01)
Years since first use of computers	97206	7.3	(0.01)	3.0	(0.01)	7.1	(0.01)	7.8	(0.02)	0.7	(0.02)
Percent correct on science content-knowledge items (%)	97206	43.6	(0.11)			43.6	(0.13)	43.8	(0.19)	0.2	(0.23)
Reading score	97206	471.8	(0.47)	94.7	(0.28)	475.9	(0.56)	463.8	(0.68)	-12.0	(0.80)
Reading fluency score (percentile)	97206	52.7	(0.12)	28.5	(0.05)	52.5	(0.14)	52.8	(0.19)	0.2	(0.23)

Note: Standard errors in parentheses. The international average is based on 50 countries/economies which administered the complete ICT familiarity questionnaire in 2018; Austria and Germany, which are included in Figure 1, are not included.

4.2. Videogaming, behavioral tendencies and procedural science knowledge

4.2.1. Single item

We first illustrate our findings with a single item from the PISA 2018 science assessment. This item (CS615Q07TA) is similar to Question 1 in *RUNNING IN HOT WEATHER*: it features a simulation with multiple input variables (controlled by the test-taker) and multiple output variables, whose values are shown, after each simulation run, in a table (together with the corresponding input values). Just like Question 1 in *RUNNING IN HOT WEATHER*, test-takers a single simulation run, using values provided to them in the instructions, is sufficient to generate the data required to answer the question correctly. However, the number of simulations that test-takers can run is not limited; students can freely explore the environment.

Table 1 indicates differences in behavioral tendencies between gamers and non-gamers in the sample task. Gamers spent an average of 19.3 seconds before taking their first action, while non gamers spent an average of 22.4 seconds, a difference of 3 seconds or around 15%. In addition, gamers logged an average of 3.5 simulation runs on the sample item, while non gamers logged on average of 0.4 fewer runs (3.2), a difference of around 10%. This illustrative item appears to be a difficult item (few students respond correctly) and gamers appear to perform marginally worse: 22% of gamers responded correctly to the sample item, while 24% of non-gamers did.

When we control for background characteristics in Table 2 we observe that the difference in time elapsed to the first action and the number of actions performed between gamers and non-gamers is reduced by half: other things being equal the difference in time on task associated with gaming is reduced to 1.6 seconds (from 3 seconds) and the difference in the number of simulation runs is reduced to 0.19 runs (from 0.37 runs). In the sample item gamers appear to underperform compared to non-gamers, a difference that remains statistically significant but is quantitatively small (2.0 percentage points when not controlling and 2.2 percentage points when controlling for background characteristics).

Table 2

Gaming-related differences in behaviour and success in simulation-based science items (sample task)

	Dependent variable:											
	Number of simulation trials				Time to first action (seconds)				Proportion correct			
	Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
Independent variables:	coef.	S.E.	coef.	S.E.	coef.	S.E.	coef.	S.E.	coef.	S.E.	coef.	S.E.
Gamer	0.375***	(0.039)	0.193***	(0.041)	-3.033***	(0.209)	-1.568***	(0.220)	-0.020***	(0.005)	-0.022***	(0.005)
Years since first use of computers			-0.019**	(0.007)			-0.083*	(0.036)			0.002**	(0.001)
Percent correct on science content-knowledge items (%)			-0.008***	(0.001)			0.088***	(0.005)			0.006***	(0.000)
Reading fluency score (percentile)			-0.002**	(0.001)			-0.046***	(0.004)			0.001***	(0.000)
Boy			0.500***	(0.038)			-3.833***	(0.214)			-0.001	(0.005)
Index of economic, social and cultural status (ESCS)			0.016	(0.020)			-0.546***	(0.114)			0.026***	(0.002)
Number of observations	43191		43191		42832		42832		43037		43037	

Notes: symbols next to coefficients indicate statistically significant results (*: p<.05, **: p<.01, and ***: p<.001). All models include a constant (not reported). The international average is based on 50 countries/economies which administered the complete ICT familiarity questionnaire in 2018; Austria and Germany, which are included in Figure 1, are not included.
Source: PISA 2018 database.

4.2.2. General patterns

The pattern observed on this single item reflects a more general pattern, whereby gamers tend to log a greater number of actions on interactive, simulation-based items, and to start interacting with the item earlier than non-gamers. Table 1 reveals that when we examine all target items gamers are, on average at the 48.5 percentile of the time needed to take the first action while non gamers are at the 51.8 percentile, a difference of over three percentiles. Meanwhile, gamers are on average at the 52.5 percentile of the distribution of number of simulation runs while non-gamers are at the 51.1 percentile, a difference of 1.4 percentiles. Across all 8 interactive, simulation-based items, the average correct response rate was similar among gamers and non-gamers: it was 44.8% among gamers and 44.0% among non-gamers.

Because differences reported in Table 1 could be due to compositional differences in 15-year-old gamers and non-gamers, in Table 3 we report results while controlling for background differences. Results indicate that differences in the background characteristics of gamers and non-gamers explain around two thirds of the observed differences in time-to-first-action and around half of the differences in the number of actions taken by gamers and non-gamers. Other things being equal, on average gamers are 1.3 percentiles below non-gamers in the distribution of time to first action and 0.7 percentiles above non-gamers in the distribution of information harvesting (number of simulations run). The difference between observed differences and differences estimates after accounting for compositional differences are mostly due to the fact that boys are more likely to be gamers but also to adopt behaviors such as a rapid transition into action and to over-explore the problem space. Other things being equal, on average boys are five percentiles below girls in the distribution of time to first action and 1.3 percentiles above girls in the distribution of information harvesting (number of simulation runs performed). Individuals who have greater reading fluency have a faster transition into action and greater information harvesting and so are individuals with greater experience using digital devices. Students with greater science content knowledge have slower transitions into action and greater information harvesting.

Table 3 also reveals that after accounting for compositional differences in teenage students who play videogames daily and those who do not, no differences in overall performance in procedural science knowledge could be identified: gamers and non-gamers display similar levels of achievement on these interactive, simulation-based items. However, they reach a solution in slightly different ways. By contrast, we find that boys, students with greater reading fluency, students higher content knowledge in science and students with a larger number of years spent using digital devices have higher levels of achievement in procedural science tasks than other students with similar characteristics.

Table 3

Gaming-related differences in behaviour and success in simulation-based science items (8 items)

Dependent variable:	Number of simulation trials (percentile)				Time to first action (percentile)				Percent correct (%)			
	Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
Independent variables:	coef.	S.E.	coef.	S.E.	coef.	S.E.	coef.	S.E.	coef.	S.E.	coef.	S.E.
Gamer	1.415***	(0.158)	0.714***	(0.169)	-3.257***	(0.160)	-1.347***	(0.167)	0.751**	(0.243)	-0.044	(0.246)
Years since first use of computers			0.177***	(0.028)			-0.107***	(0.026)			0.619***	(0.038)
Percent correct on science content-knowledge items (%)			0.090***	(0.003)			0.121***	(0.003)			0.251***	(0.004)
Reading fluency score (percentile)			0.039***	(0.003)			-0.052***	(0.003)			0.113***	(0.004)
Boy			1.272***	(0.162)			-4.977***	(0.155)			0.766***	(0.229)
Index of economic, social and cultural status (ESCS)			1.860***	(0.088)			-0.075	(0.083)			4.989***	(0.124)
Number of observations	97206		97206		97206		97206		97206		97206	

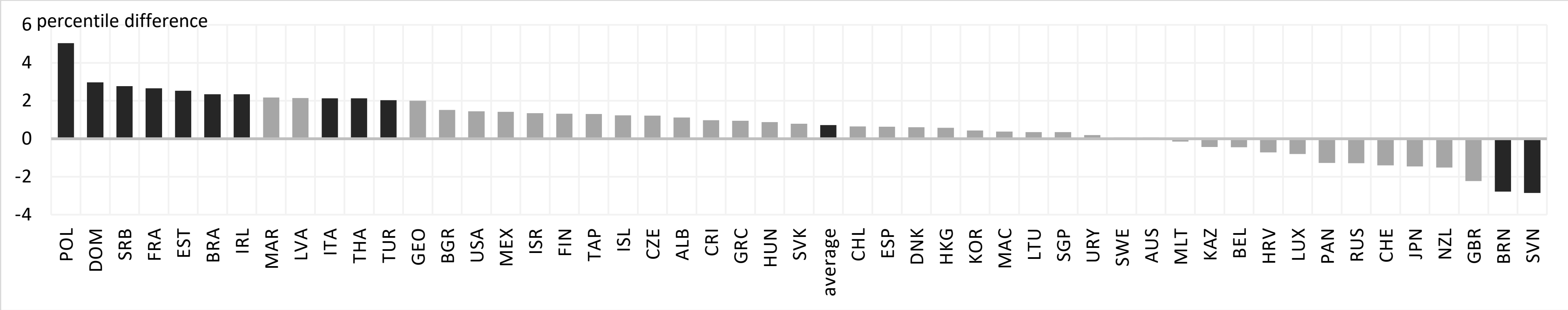
Notes: symbols next to coefficients indicate statistically significant results (*: p<.05, **: p<.01, and ***: p<.001). All models include a constant (not reported). The international average is based on 50 countries/economies which administered the complete ICT familiarity questionnaire in 2018; Austria and Germany, which are included in Figure 1, are not included.
Source: PISA 2018 database.

Results presented in Table 3 illustrate average findings across the 50 national samples that took part in the PISA 2018 study and administered the optional ICT questionnaire. As such, they reveal aggregate patterns across a large number of independent samples, each representing a population with different levels of prevalence of gamers and non-gamers, average levels of achievement, cultural preferences and potential preference for different test taking and problem solving behaviors. Figure 2 illustrates country specific results on the association between gaming and time to first action and between gaming and information harvesting after accounting for background characteristics. Results reveal a high degree of consistency in the direction of associations, although the null of no association can be rejected only in a subset of countries at the 5% level because, due to small sample size, associations are imprecisely estimated at the individual country level.

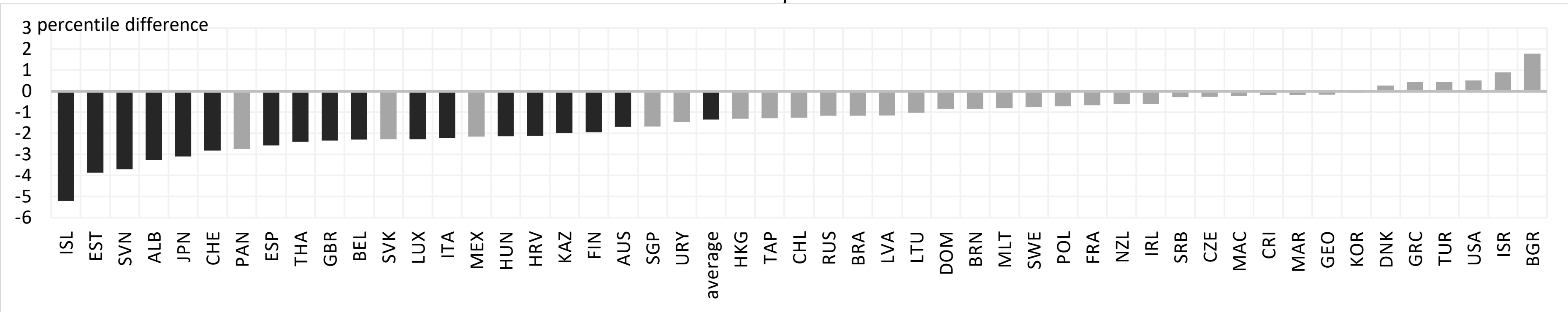
Figure 2

Gaming-related differences in problem-solving behaviour, by country

Panel A: Number of simulation trials



Panel B: Time to first action



Note: Each bar corresponds to the difference between gamers and non-gamers, after adjusting for possible confounding variables (model 2), estimated on 50 national sample (countries/economies that administered the complete ICT familiarity questionnaire in PISA 2018). Statistically significant differences (p < .05) are marked in a darker tone.

Source: PISA 2018 database.

4.2.3 Moderating effects: gender differences in the association between videogaming, behavioral tendencies and achievement

We explore gender differences in estimated associations in Table 4. Results reveal that, other things being equal the gender gap in how fast test takers move from seeing an item to taking their first action is smaller among gamers than among non-gamers. Among non-gamers boys are almost 6 percentiles below girls in the distribution of time to first action, on average. However, while male gamers are similar to male non-gamers, female gamers are on average about 3 percentiles below female non-gamers. By contrast, gaming is associated with wider gender gaps in information harvesting: among non-gamers, boys are about one percentile above girls in the distribution of simulation trials; a difference that widens significantly among gamers, by an additional 1.3 percentile points. Interestingly, while among gamers there are no gender differences in achievement in procedural science knowledge, gender differences emerge among gamers. Female gamers underperform compared to female non-gamers (by around 2.5 percentage points) and compared to male gamers, while male gamers outperform male non-gamers (by around 1.3 percentage points) and female gamers.

Table 4

Gaming-related differences in behaviour and success in simulation-based science items, by gender

	Dependent variable:					
	Number of simulation trials (percentile) Model 3		Time to first action (percentile) Model 3		Percent correct (%) Model 3	
Independent variables:	coef.	S.E.	coef.	S.E.	coef.	S.E.
Gamer*Girl	-0.389	(0.301)	-3.170***	(0.272)	-2.428***	(0.407)
Gamer*Boy	1.269***	(0.214)	-0.350	(0.212)	1.322***	(0.309)
Years since first use of computers	0.173***	(0.028)	-0.111***	(0.026)	0.612***	(0.038)
Percent correct on science content-knowledge items (%)	0.090***	(0.003)	0.121***	(0.003)	0.251***	(0.004)
Reading fluency score (percentile)	0.039***	(0.003)	-0.052***	(0.003)	0.113***	(0.004)
Boy	0.845***	(0.190)	-5.758***	(0.188)	-0.301	(0.274)
Index of economic, social and cultural status (ESCS)	1.854***	(0.088)	-0.083	(0.083)	4.985***	(0.124)
Number of observations	97206		97206		97206	

Notes: symbols next to coefficients indicate statistically significant results (*: p<.05, **: p<.01, and ***: p<.001). All models include a constant (not reported). The international average is based on 50 countries/economies which administered the complete ICT familiarity questionnaire in 2018; Austria and Germany, which are included in Figure 1, are not included.
Source: PISA 2018 database.

6. Conclusions

Our study indicates that already before the COVID-19 pandemic, videogaming was popular worldwide, especially among boys. During the COVID-19 pandemic, existing trends accelerated and in 2020 videogaming was one of the fastest growing forms of entertainment (Witkowski, 2021). Much of the debate in the popular press and the academic literature on videogames has focused on the effects of gaming on physical health, mental health and academic achievement. Despite what are often-sensational claims on the negative consequences of videogaming for children's cognitive development and their well-being, the research literature indicates that videogames can effectively develop several cognitive skills, such as executive control as well as visual and attentional skills (Basak et al. 2008; Green and Bavelier 2006). In this work we built upon prior work identifying a strong association between videogaming and self-reported problem solving skills (Adachi & Willoughby, 2013) to identify if gamers differ from non gamers in how they approach scientific problems. We rely on an interactive assessment administered to representative samples of 15-year-old students in 50 education systems worldwide to assess which behavioral tendencies gamers display and if these translate into higher or lower achievement in science.

6.1. Limitations and future directions

Our study suffers from a number of limitations. First, the evidence we present is descriptive and does not establish a causal link; multiple explanations are possible for the associations found. The fact that we observe similar patterns in countries with different prevalence of gaming and in which the prevalence of gaming changed rapidly over time suggests that selection processes are unlikely to fully explain our results, but future work should attempt to complement our observational evidence with experimental or quasi-experimental evidence. Second, because PISA data do not contain any information on the type of games different individuals play, it is impossible within our study to establish if behavioral differences observed, especially differences between males and females, reflect differences in the types of games that they typically played or if they reflect other dimensions across which boys and girls differ. Third, our results reflect behavior observed in the context of the administration of the PISA test in 2018.While a wide range of national contexts are covered in this study, general conclusions that refer to age-groups, countries, or periods that were not observed must remain cautious.

6.2. Discussion

Overall results support our hypothesis that, at the margin, gamers adopt different problem solving strategies when compared to non-gamers who have similar background characteristics. In particular, gamers have faster transition times between being exposed to a problem and starting to engage with it, i.e. they spend less time reading written instructions. Furthermore, gamers engage in greater information harvesting than non-gamers.

These results suggest that gamers approach problems slightly differently from non-gamers with no difference on overall achievement. However, the gender specific analyses suggest that such result might be due to two competing effects: a fast transition into action could be associated with lower achievement while more extensive exploration could be associated with higher achievement. Although effects are small according to conventional levels (Cohen, 1988), when these are reliably estimated, what is typically considered to be a very small effect for the explanation of single events, can have potentially consequential effects (Funder & Ozer, 2019).

Fast transitions into action may, in the particular situation of an assessment, be an inadequate response. Our study focuses on relationships observed in the teenage years, when many teenagers and their families make important educational, training and labour market decisions, decisions that are often determined by the opportunities they have because of their achievement in tests and assessments. In the teenage years the executive function of inhibitory control is still developing (Kuhn 2009) and many teenagers experience, as a result of these neurological changes, increased impulsivity, difficulty in evaluating long-term benefits *vis a vis* short term costs (Sapolsky, 2017). These effects may affect all but may be especially marked in some. In particular, gamers may be especially susceptible to impulsivity and restlessness and, as such, may fail to put an adequate amount of time reading instructions when completing assignment or doing other work for school.

To the extent that our finding on the faster transition into action among gamers applies to all tests, rather than narrowly to science tests administered in low-stakes settings, it could inform the design and administration of tests and assessments. Even if results were to reflect behavioural tendencies of individuals who are likely to become regular videogamers rather than causal effects of gaming, they suggest that some students spend too little time understanding what is required of them in the assessment situation. If results were causal, since videogaming is increasingly prevalent, a growing number of teenagers can be expected to engage in behaviours that lead them to spend too little time on familiarising themselves with the requirements of the test. This is especially relevant since in recent years, tests and assessments administered in school have become more diverse, in order to exploit the affordances of computer-based assessments, and students cannot rely on their experience of past tests to understand what is required to solve a problem. Modern, computer-based tests include tools such as simulations, scenarios, and games that replicate the diverse and rich contexts of performance in real life (Shute and Ventura, 2013; Quellmalz and Pellegrino, 2009).

Assessment developers can ensure that instructions are carefully read and understood by test takers, particularly when test questions or what is required of test-takers is significantly different from what is generally expected of them in tests or from was expected of them in previous questions in the same test, i.e. if they deviate from the usual status quo. Similarly, teachers and other education professionals can provide additional input and support to ensure that instructions are adequately understood by all, together with feedback on how many students fail their tests because of lack of understanding of what is required rather than ability to solve the test.

At the same time, the extensive exploration of the problem space in order to obtain data in support of future decisions often corresponds to a positive behaviour with multiple advantages in authentic problem situations. Active learning approaches that encourage learners to explore a system (even if this means making mistakes or taking longer to reach a solution) have been shown to be superior to learning based on following instructions and avoiding making mistakes, especially in novel situations (Bell & Kozlowski, 2008). Exploration and experimentation during the learning process activate individuals' metacognition, i.e. their capacity to plan, monitor and revise behaviour given emerging stimuli (Bell & Kozlowskil 2008) and, by so doing, enhance learning and transfer (Keith & Frese, 2005). Social, technological and economic transformations reduce the need for individuals to memorise facts while yielding increasing returns to those who are able to explore problem spaces in innovative ways (OECD, 2013). Technological innovations are reshaping the skills that are needed to participate successfully in the labour market so that there is now a markedly higher share of nonroutine tasks, i.e. tasks for which the capacity to practice inductive reasoning is beneficial (Autor, Levy, & Murnane 2003; Ikenaga & Kambayashi, 2010; Spitz-Oener, 2006). Assessment developers and teachers may find inspiration in games (and videogames) to develop scenarios in which students can practice effective strategies for information harvesting.

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