Computers in Human Behavior 64 (2016) 108–116

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Full length article

Laypersons' digital problem solving: Relationships between strategy and performance in a large-scale international survey

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ARTICLE INFO

Article history:
Received 4 April 2015
Received in revised form
6 June 2016
Accepted 15 June 2016
Available online 30 June 2016

Keywords:
PIAAC
Electronic problem solving
Action count
Response time
Problem solving strategy

ABSTRACT

This study examines the role of online data as indicators of the cognitive processes involved in problem solving in a technology-rich environment. More specifically, we analyze the relationship between response time, logged action count and task outcomes in a sample of over 23,000 adults from 16 countries who participated in the Problem solving in technology-rich environments (PS-TRE) assessment as part of the Program for the International Assessment of Adult Competencies (PIAAC) survey. Based on a selection of tasks used in the PS-TRE assessment, the results show that while time on task may have a heterogeneous effect on a population level depending on task difficulty, action count is positively linked to task accuracy. The data also reveals a surprisingly varied and task-specific relationship between those variables.

1. Introduction

In most developed countries, the past two decades have witnessed a tremendous increase in laypersons' access to and use of digital technologies. In the U.S., for instance, the percentage of homes with an Internet connection grew from 34% in 2000 to about 70% in 2012 (Pew Internet project, 2012). Similar percentages are observed in Europe and other parts of the World. Traditional gaps associated with gender, education, ethnicity, income or age – though still present – are decreasing (Gombault, 2013; Pew Generations, 2010). The worldwide dissemination of digital technologies has raised new questions regarding the societal and cognitive challenges resulting from widespread access to, and effective mastery of technological tools.

People use the Internet for a broad range of personal, educational, occupational and civic purposes. Email and information search still represent the most frequent types of uses, but other activities, such as online banking, shopping, looking for health-related information, planning and organizing activities or social networking have become increasingly popular (Pew Internet project, 2012). Digital environments require the usage of specific tools, like computer desktops, e-mail systems, text processing software, menu frames, index tables, search engines, and so forth. Computer users have to learn to interpret graphical information (Windows, frames, icons) and to operate hardware and software artifacts such as scroll bars, buttons or links.

Moreover, most tasks involve more than a mere sequence of routinized actions; case-based reasoning, and metacognitive and self-regulatory processes as well (Azevedo, Moos, Witherspoon, & Chauncey, 2010; Lazonder & Rouet, 2008; Naumann, Richter, Christmann, & Groeben, 2008; Organization for Economic Cooperation and Development, 2009; Salmerón, Kintsch, & Kintsch, 2010). Therefore, to perform computer tasks – such as searching for information on the net, organizing folders, extracting information from large data sets, shifting across software applications and windows-more abstract problem solving skills are required to be employed behind computer skills.

A problem is generally defined as a situation where people try to reach a certain goal through the use of various operators and resources (Chi & Glaser, 1985). In recent decades, there has been a growing interest for problems that require people to make use of large amounts of information. These are typically "ill-defined" problems, in that some aspects of the goal, the operators and resources are left for the problem solver to find out. The phrase "information problem solving" (Brand-Gruwel, Wopereis, & Walraven, 2009; Eisenberg & Berkowitz, 1990; Moore, 1995) was proposed to denote this type of problems. Brand-Gruwel, Wopereis, and

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http://dx.doi.org/10.1016/j.chb.2016.06.018
0747-5632/

Vermetten (2005) define information problems as “tasks or assignments that require [students] to identify information needs, locate corresponding information sources, extract and organize relevant information from each source, and synthesize information from a variety of sources.” Most activities involving the use of information and communication technology may qualify as information problem solving, as these technologies are primarily meant to support the production, dissemination and access to various types of information (whether verbal, pictorial, numerical or other). Research suggests that most people experience difficulties while solving information problems on a computer (For a review, see Lazonder & Rouet, 2008).

Program for the International Assessment of Adult Competencies (PIAAC) was the first major international assessment predominantly administered using computer-based testing. The purpose of PIAAC was to “break new ground, in particular, by extending the concept of literacy to problem solving competencies in a technology rich environment” (PIAAC Expert Group in PS-TRE, 2009). Thus, the purpose of the PS-TRE domain was not to evaluate adults’ familiarity with information and communication technologies per se, but rather to assess their ability to use digital resources to access and process information effectively in purposeful non-routine settings. In this sense, PS-TRE matches the three criteria proposed by Funke (2010) to characterize complex problem solving: Elements relevant to the solution process are large (complexity), potentially pertaining to multiple computer environments or applications; they are highly interconnected (connectivity), as for instance in email, web page or spreadsheet applications, and dynamically changing over time (dynamics), which is typical or work with computerized systems.

By reason of the limited capacity of working memory, problem solving is a stepwise process gradually leading toward the goal state (Chi & Glaser, 1985; Ward & Morris, 2005) through a series of complex cognitive operations: mentally representing the problem space; problem finding, or understanding the nature of the problem; problem shaping, or defining a set of subgoals and steps; and problem solving per se, that is, using strategies to go through the subgoals until a solution is reached, or backtracking in case of an impasse or other obstacle (Fischer and Funke, 2011; PIAAC Expert Group in PS-TRE). A general assumption of problem solving research is that component cognitive processes can be mapped into directly observable, external constructs in order to be analyzed and assessed. Problem solving, metacognition and self-regulated learning steps have been successfully observed by self-report questionnaires (Hadwin, Winne, Stockley, Nesbit, & Woszczyna, 2001; Weinstein, Schulte, & Palmer, 1987; Zimmerman & Martinez-Pons, 1986) and think-aloud protocols (Azevedo & Witherspoon, 2009; Ericsson & Simon, 1993) for decades (see Cleary, Calan, & Zimmerman, 2012; Zimmerman, 2008 for reviews).

Among other benefits, the computer delivery mode of problems also allows the automatic and objective recording of solution steps. Computers can capture all problem solver-computer interactions in log-files enabling the collection of timed navigational actions (e.g.: clicking on links while looking for information on a website) and activities related to the usage of computer applications and functions (e.g.: using the sort button, creating or copying a text, opening up a window). This paves the way for new approaches to problem solving skill assessment, ones that take into account not just the outcome, but also the strategies used by problem solvers to achieve their goals. The analysis of logged data of human-computer interactions became the focus of several research studies during the last few years, yet no systematic approach emerged that is capable of evaluating the efficiency and the impact of problem solving processes (Biswas, Jeong, Kinnebrew, Sulcer, & Roscoe, 2010; Ifenthaler, 2008; Zimmerman, 2008).

The present study examines the relationship between the time spent on task, the number of problem solving actions and the outcome of PS-TRE tasks. It is expected that the collection and analysis of the above online PIAAC PS-TRE data will contribute to improving the description of proficiency in the domain of information problem solving.

2. Relationship between time, action count and outcome in digital problem solving

Traditionally, skill assessment is based on test outcomes. However, time on task has also a long history in skill assessment and has been considered an important feature of task solution processes for decades (Chang, 2014). Moreover, some studies show that time itself can serve as the measure of proficiency, especially for automated tasks characterized by general high performance. In the domain of HCI, the study by Goldhammer, Naumann, and Keßel (2013) revealed that the response speed to a test assessing the basic ability to handle mouse, keyboard, menu systems and to perform simple file and text operations, was positively related to the test outcome. On the other hand, the within-person speed-accuracy tradeoff (i.e. one can give up some accuracy for higher speed and vice versa) has been a well-known phenomenon in information processing for decades (Hick, 1952). In the case of complex electronic problem solving tasks, a lower solution time was linked to a more user-friendly environment (Antonenko and Niederhauser, 2010; Dorum & Garland, 2011; Padovani & Lansdale, 2003) and a more expert-like and efficient solution process (Lazonder, Biemans, & Worpeis, 2000; Zoanetti, 2010).

At the level of the population, the response time/accuracy relationship is often explained under dual-process models. According to these models, controlled processes are executed slowly under attentional control while automated processes are fast and do not reacquire attention (Schneider & Shiffrin, 1977). Problem solving tasks comprise control processes per se. Scherer, Greiff, and Hautamäki (2015) found evidence for positive correlation between complex problem solving time on task and accuracy. The authors concluded that complex problem solving encompasses both ability and time on task factors. They explain the positive time on task and accuracy relationship by the controlled processes involved in solving non-routine problems. At the same time, low level processing of text comprehension (see Kintsch, 1998) or basic computer handling – such as using a mouse – consist mostly of automated processes. By analysing PIAAC computerized reading and problem solving task solution behaviours, Goldhammer et al. (2014) showed the group-level heterogenic time effect of controlled and automated processes. Their cross-tasks and across-domains linear mixed models showed that for PIAAC problem solving, more time on task was associated with higher chances for a correct outcome. The association was even stronger as tasks got more difficult and decreased for high skill test-takers. For reading tasks, the opposite tendency was observed. There was a negative relationship between time on task and outcome. Moreover, the negative association became stronger for easier tasks and increasing skill level. However, they did not succeed in showing a time effect at a task level. In another study, Goldhammer, Naumann, and Greiff (2015) discovered that the relation of task accuracy and response time in the Raven’s Advanced Progressive Matrices test differs across task difficulty and respondents’ skill levels. In general, the time on task had a negative effect on accuracy albeit for difficult tasks and less skilled respondents its impact was less negative or occasionally, positive.

Although the use of action count is less widespread than the investigation of response time effect, we think there is a lot to learn from principled analysis of actions taken during computerized