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Sequential actions as markers of behavioural and cognitive processes: Extracting empirical pathways from data streams of complex tasks

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A B S T R A C T

This paper presents a novel exploratory method to extract information about behavioural and cognitive processes that occur during the performance of complex tasks. The methodology is framed in a structure where process data on interactions between the task performer and the task space environment are captured in a data stream for big data analytics.

We begin by describing a reductionist approach that involves deconstructing complex processes into constituent parts. We extend this approach by looking at sequences of these constituent parts with the aim of detecting patterns in a person's action pathways. We propose the exploration of these pathways as indicators of underlying behavioural and cognitive processes. Current sequence-based approaches are presented and a proposed approach in dealing with sequences as empirical pathways is demonstrated using data stream from an interactive and collaborative online-administered complex task. These empirical pathways were visualised as directed graphs and an exploratory network analysis is proposed to examine specific features of the emergent paths.

General challenges encountered during the development of such a method are described and specific future challenges that we foresee in transitioning from an exploratory phase to a confirmatory phase are examined. Finally, possibilities for further research as well as future applications are discussed.

1. Preliminaries

This is a methodological paper that presents a novel approach for extracting and exploring sequences of meaningful actions from data streams. Although the approach is general in the sense that it can be applied in different analytical frameworks and research design contexts, we present this approach by applying it to an analytical framework for quantifying complex tasks using automated scoring schema.

Quantifying complex tasks is a challenge in educational measurement and assigning qualitative ordinal marks to this quantification is even more of a challenge because of the difficulty in differentiating between levels of any complex construct. For example, differentiating between low and high levels of arithmetic skill is far easier than it is for resource management

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skill. Quantifying complex tasks is important because competence in these types of tasks form a broad class of skill resource that will become increasingly important as the world moves towards inter-connectedness in the 21st century (Binkley et al., 2012).

From an educational perspective, developing skills on complex tasks will be a mandate for 21st century education. In line with the imperative that something cannot be improved unless it can be measured, educators globally need to handle the shift in skill requirement and measurement challenges that come along with other 21st century skills. Complex tasks such as collaborative problem solving (CPS) encourage within group accountability, ability to ask questions and justify responses, flexibility in reasoning, and reflective skills (Baghaei, Mitrovic, & Irwin, 2007; Soller, 2001; Webb, Troper, & Fall, 1995). Component skills necessary for performing complex tasks are therefore transferrable to diverse real world settings. Rummel and Spada (2005) have shown that medical practitioners and psychologists who collaborated effectively in an online environment while attempting complex tasks outperformed a control group in relation to knowledge of collaboration skills. In business marketing environment, working on realistic tasks for problem based learning can develop forward reasoning or inductive skill (Arts, Gijselaers, & Seers, 2006). It is not surprising that educators have an interest in teaching these processes and studies of CPS in particular have taken place in multiple and diverse fields (Arts et al., 2006; Liao & Ho, 2008; O'Neil, Chuang, & Chung, 2003; Pazos, Micari, & Light, 2010; Rummel & Spada, 2005).

1.1. Complex tasks

Complex tasks in this context are those that cut across multiple domains of knowledge, are not *always* algorithmically solvable, involve numerous skills, and require some creative ability. Complex tasks can be characterised by:

- their reliance on multiple processes
- lack of clarity about how these processes might interact or the sequence in which they will most effectively take place
- multiple and unlike factors or artefacts constituting the task
- lack of clarity about the roles that these factors or artefacts play.

The study of how individuals engage with complex tasks is synonymous with problem solving. Exploration of the processes employed in problem solving or in engaging with complex tasks provides information about the cognitive skills which underlie successful resolution of the problems or tasks (O'Neil, 1999; O'Neil, Chuang, & Chung, 2003: Care & Griffin, 2014). These cognitive skills can be demonstrated through behaviours which are captured in the form of processes attempted or completed. As with other cognitive skills, we infer their existence through behaviours hypothesised to indicate these skills. We can then situate these behaviours within frameworks based on the model of hierarchical complexity (MHC; Commons & Richards, 1984; Commons, Trudeau, Stein, Richards, & Krause, 1998). For example, from an individual's behaviour in writing a paragraph in text, we would assume that the individual has understood the processes involved in constructing a grammatical sentence which conveys meaning. The cognitive capabilities underlying these processes would include knowledge of how letters combine to form words, and how words linked with each other denote meaning. In this context of complex tasks, the processes would include scoping the task space, finding patterns, forming rules, generating hypotheses, and testing hypotheses.

Although MCH and quantitative behaviour-analytic theory as a whole are useful for framing and organising complex tasks into coherent structures (Commons et al., 1998), measuring performance in a complex task remains granular (see Commons, 2008). From a measurement perspective, complex tasks are a challenge to quantify and the underlying constructs are not fully captured using conventional dichotomous (i.e., success-failure) scoring systems. One way of quantifying these tasks is to use a reductionist approach. Although we talk of this approach as reductionist in nature, the sense is *not* in the strict philosophical doctrine of reductionism[1] that the whole is deducible from the parts but rather one that applies the explanatory tenets of a subtype of this philosophy towards *compositional* (Gillett, 2007) or *mechanistic* (Wimsatt, 2006) reductions to specific methodological frameworks. These compositionally reductive frameworks are used in the contextual application of the measurement tools for complex tasks as well as in the conceptualisation of the tasks themselves. In this sense, the compositional or mechanistic reductions lead to complex constructs being broken down – or reduced – into simpler, more quantitatively manageable constructs. Ideally, these smaller components have a more directly observable set of indicators.

To illustrate this concept of applying compositional reductionism to complex tasks, suppose we need to measure driving skills. Holistic quantification approaches often lead to quantitatively unsupportable rhetorical excess by way of having the *average* response to the question ‘How good a driver are you?’ is ‘I'm above average’.[2] This is understandable given the complex nature of the task that is ‘driving’. However, we will be able to adequately measure this construct in a manageable form if we reduce this construct, and break down ‘driving skill’ into the following components for example, 1) number of demerits accumulated during a 3 month period, 2) average difference between actual speed and the speed limit, 3) average fuel efficiency as an indirect indicator of driving efficiency, 4) average vehicle maintenance costs as a proxy for reliability and

[1] In terms of higher-level vs lower-level systems. See Nagel (1961) and Putnam (1973) for context in the natural and social sciences respectively.

[2] Although this may seem like a joke, the existence of a phenomenon called *illusory superiority*, a type of cognitive bias in which the majority of group members think they are above average, is supported by research (e.g., Giladi & Klar, 2002; Svenson, 1981).