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Case studies of mental models in home heat control: Searching for feedback, valve, timer and switch theories

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ABSTRACT

An intergroup case study was undertaken to determine if: 1) There exist distinct mental models of home heating function, that differ significantly from the actual functioning of UK heating systems; and 2) Mental models of thermostat function can be categorized according to Kempton's (1986) valve and feedback shared theories, and others from the literature. Distinct, inaccurate mental models of the heating system, as well as thermostat devices in isolation, were described. It was possible to categorise thermostat models by Kempton's (1986) feedback shared theory, but other theories proved ambiguous. Alternate control devices could be categorized by Timer (Norman, 2002) and Switch (Peffer et al., 2011) theories. The need to consider the mental models of the heating system in terms of an integrated set of control devices, and to consider user's goals and expectations of the system benefit, was highlighted. The value of discovering shared theories, and understanding user mental models, of home heating, are discussed with reference to their present day relevance for reducing energy consumption.

1. Introduction

Mental models can be thought of as internal constructs that explain human behaviour (Wickens, 1984; Kempton, 1986). The notion has been associated with many domains over the last 20 years, including domestic (Kempton, 1986), transport (Weyman et al., 2005) and military (Rafferty et al., 2010). Mental Models have formed the basis of strategies to improve interface design (Carroll et al., 1987; Williges, 1987; Norman, 2002; Baxter et al., 2007; Jenkins et al., 2010), to promote usability (Norman, 2002; Mack and Sharples, 2009; Jenkins et al., 2011; Branaghan et al., 2011; Larsson, 2012), and to encourage sustainable behaviour (Kempton, 1986; Sauer et al., 2009; Lockton et al., 2010) amongst many others. In 1986, Kempton described two distinct 'forms' of mental models of thermostat function that were prevalent in the population of that time. He proposed that the form of model held, could result in significant variations in the amount of energy consumed due to home heating, by promoting different patterns of manual thermostat adjustment. Currently in the UK, 25% of carbon emissions are from domestic customers, 58% of which is due to domestic heating. The UK has legislated to cut 80% of greenhouse gas emissions by 2050 (Climate Change Act, 2008). Since Kempton's study, almost three decades have passed and technology has changed. It seems appropriate, therefore, to explore if Kempton's (1986) shared theories can still be identified, and if so, to question if they remain relevant to design strategies targeted at combatting climate change.

The term 'mental model' is used in different domains to mean different things (Wilson and Rutherford, 1989) and even within a domain, can be used to describe internal constructs that differ significantly in terms of content, function or perspective (Richardson and Ball, 2009; Revell and Stanton, 2012). The form of mental model descriptions may have similarities to the way other types of models (e.g. process models or logic models) that do not depict internal constructs, are represented, resulting in confusion when interpreting outputs. Specificity in the type of mental model is considered essential for commensurability when conducting research (Norman, 1983; Wilson and Rutherford, 1989; Bainbridge, 1992; Revell and Stanton, 2012). The authors ask the reader to bear the extended clarification of the way the term is used to this paper. The intention is to allow sufficient understanding to determine the relevance and applicability of the findings presented. This paper refers to mental models in three different ways: 1) in terms of its function; 2) in terms of its source, and; 3) in terms of its individuality.

In terms of function, the definition most fitting is a "device model". Kieras and Bovair (1984) adopted this terminology to describe a mental model held by a user of how a device works. It includes a set of conceptual entities and their interrelationships (Payne, 1991). In this paper, the device of interest is the home heating system, and we seek to describe the conceptual entities and

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their interrelationships held by users. Device models, as a type of mental models, may be incomplete, inaccurate, and inconsistent (Norman, 1983). The authors believe that understanding where omissions, inaccuracies and inconsistencies occur in users device models of home heating, could provide insights into how to reduce energy consumption resulting from non-optimal operation.

In terms of its source, this paper adopts Norman's (1983) definition of a "User Mental Model"(UMM). He describes this as "the actual mental model [of a target system] a user might have", that can only be gauged by undertaking observations or experimentation with the user. In this paper we are seeking the model of the home heating system held internally by a user. As we cannot access this model directly, we have adopted a method appropriate to our aims to gain data to describe the user mental model.

In terms of the individuality of mental models, we also refer to Kempton's (1986) 'shared theory'. A 'shared theory' is derived by an analyst through the identification of similarities in separate UMMs of individuals. These individuals are within a social group, who may share similar types of individual goals. A 'shared theory' differs from concepts such as 'shared' or 'team' mental models that refer to shared knowledge structures within a team or group who are working towards group goals (Richardson & Ball). The benefit of identifying shared theories of home heating, is broader reach when targeting strategies, to combat climate change, at individuals within the home.

The 2 shared theories identified by Kempton (1986) were described as 'valve' and 'feedback'. Users with a valve shared theory, considered changes in the set point of their thermostat to be controlling the intensity of heat in their furnace, with the onus on the user to ensure a comfortable home temperature. Users with a feedback shared theory, considered their responsibility merely to select the desired thermostat set point. The thermostat would maintain comfort in the home by controlling the boiler operation period, in response to measurements of house temperature. Kempton (1986) referred to this latter theory as an 'amateur theory' of home heating, as it is a simplistic version of the actual way the heating system works. Kempton (1986) described how different shared theories may predict different behaviour patterns of thermostat set point adjustment. He discovered that holders of valve theory, had a unique behaviour characteristic absent in those holding feedback theory. At night, valve theorists regularly set the thermostat back to below normal comfort levels, which Kempton (1986) described as 'night set back'. Kempton (1986) proposed that despite the valve theory being less accurate than the feedback theory, this behaviour characteristic was likely to result in greater energy savings overall.

Since Kempton (1986), additional shared theories of thermostat function have been proposed in the literature such as 'Timer' (Norman, 2002) and 'Switch' (Peffer et al., 2011). Users holding the timer theory are thought to select greater values of set point, when longer periods of boiler operation are desired. Those holding the switch theory are thought to use the thermostat merely as an on/off switch. Both of these theories assume the user, not the system, is responsible for maintaining a comfortable house temperature. Norman (2002) and Peffer et al. (2011), do not refer to studies which informed these types of shared theory, nor do they describe distinct behaviour characteristics which may influence energy consumption. When investigating current user mental models of home heating, the authors therefore consider it relevant to determine if these, or new shared theories of home heating, could be identified. Understanding how resulting shared theories associate with energy consuming behaviour could provide insights to inform novel approaches to reduce consumption.

The reader may question if Mental Models need to be accurate or is it sufficient that they are effective. Depending on context and the specific user behaviour being considered, what is considered 'effective' will vary. Kempton 1986 described how a faulty mental model of home heating control could lead to more energy efficient behaviour, than a more accurate model. Norman (1983) contends that designers and instructors should ensure a 'functional' (not necessarily accurate) mental model to enhance user interaction with a system. Norman (1986) emphasises that the appropriateness of the user's underlying model of a system is essential when troubleshooting, as the user is able to derive possible courses of action and possible system responses. Kieras and Bovair (1984) concluded that for very simple devices or procedures, there will be little value in providing a device model to users. Manktelow and Jones (1987) warn that systematic errors may result from an inappropriately simple mental model. So, taken together, the authors conclude that for simple procedures, simple devices or systematic errors that have minor consequences, a 'functional', simplified or even lack of mental model, may be effective. For more complex systems or procedures, where the need for troubleshooting is likely, or if the consequence of systematic errors is significant (as in the case of non-optimal home heating during an energy crisis), a more accurate user mental model may be needed for the effective use of devices.

Hancock and Szalma (2004), emphasised the importance of qualitative methods in revealing user intention in a way that can inform the development of design principles. Flyvbjerg (2011) argues that rich data gathered from detailed, real life situations can provide meaningful insights, that could not be gained from context-independent findings. Virzi (1992), when conducting research into usability, found 80% of problems, including the most severe, are detected with the first 4–5 subjects, illustrating how key insights can be gained with very small samples. Hancock et al. (2009) also argue that ideographic case representations are increasingly relevant for the design of human–machine systems, as advances in technology begin to focus on exploiting individual differences. Supporting these sentiments, this paper describes the results from an intergroup case study of home heating control, focussing in detail on 3 individual case studies taken from a pool of 6. The intention of this paper is to: 1) Demonstrate the existence of distinct mental model descriptions of the functioning of present day UK home heating systems, that differ significantly from actual functioning. 2) Seek evidence of Kempton's (1986), Norman's (2002) and Peffer et al.'s (2011) shared theories of thermostat function in the case study group, and 3) discuss the present day relevance of Kempton's (1986) valve and feedback models of thermostat function, to design strategies targeted at combatting climate change. Additional implications and the limitations of the study are also discussed.

2. Method

2.1. Participants and setting

The case study group was non-randomly selected and comprised mainly overseas postgraduate students with families, new to the UK, who resided in semi-detached university owned accommodation in Southampton, UK. Participants arrived in their accommodation at the start of September 2011 and used the central heating system during the autumn and winter months. Southampton has an oceanic climate, with cool winters (temperatures typically below 5 °C). The accommodation, home heating devices and levels of insulation were matched, so that variations in mental model descriptions could be attributed to characteristics of the participant, rather than the environment. The layout of the home heating devices and specific models used are shown in a diagram in Fig. 1. The Participants were recruited by letter, email and