Applied Ergonomics 57 (2016) 48–61

Contents lists available at ScienceDirect

Applied Ergonomics

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

Mind the gap – Deriving a compatible user mental model of the home heating system to encourage sustainable behaviour

Kirsten M.A. Revell*, Neville A. Stanton

Engineering and the Environment, University of Southampton, Building 176, Boldrewood Campus, Burgess Road, Southampton SO16 7QF, UK

ARTICLE INFO

Article history:
Received 25 February 2015
Received in revised form
2 February 2016
Accepted 16 March 2016
Available online 6 April 2016

Keywords:
Mental models
Design: sustainability
Behaviour change
Design model

ABSTRACT

Householders' behaviour with their home heating systems is a considerable contributor to domestic energy consumption. To create a design specification for the 'scaffolding' needed for sustainable behaviour with home heating controls, Norman's (1986) Gulf of Execution and Evaluation was applied to the home heating system. A Home Heating Design Model (DM) was produced with a home heating expert. Norman's (1986) 7 Stages of Activity were considered to derive a Compatible User Mental Model (CUMM) of a typical Heating System. Considerable variation in the concepts needed at each stage was found. Elements that could be derived from the DM supported stages relating to action specification, execution, perception and interpretation, but many are not communicated in the design of typical heating controls. Stages relating to goals, intentions and evaluation required concepts beyond the DM. A systems view that tackles design for sustainable behaviour from a variety of levels is needed.

1. Introduction

Home heating contributes 58% of domestic energy use in the UK (Department of Energy and Climate Change, 2011). Considerable differences in amount of energy used in homes results from occupant's behavioural differences (Lutzenhiser and Bender, 2008). Understanding the cause of behavioural differences in the way home heating systems are used provides an opportunity to develop approaches to encourage appropriate behaviour change for sustainability in householders. The purpose of this paper is to provide insights that could inform the design or evaluation of home heating interfaces to encourage appropriate heating control. The authors consider 'appropriate heating control' to be pragmatic operation of heating devices so householders fulfil their heating goals with minimal wasted energy. The approach taken by this paper is to apply Norman's (1986) theory of the Gulf of Evaluation and Execution to derive the form and content of a User Mental Model (UMM) that would enable appropriate heating control.

Key issues that prevent householders operating heating systems appropriately include the cognitive and physical usability of the system. Kempton (1986, 1987) proposed that variations in the way people operate their home heating thermostat, resulted from their differing 'mental models' of the way the device functioned. He found evidence that behaviour patterns associated with some mental models were more energy efficient than others, as they encouraged 'night set back'. Revell and Stanton (2014) found faulty or incomplete mental models explained non-optimal operation of home heating devices; where energy was either being wasted, or heating goals failed to be achieved. Considerable energy savings could be made if heating systems were effectively programmed (Gupta et al. in Combe et al., 2011), yet in a study by Combe et al. (2011), 66% of participants were unable to complete the set programming task. Peffer et al. (2011) discuss how users can waste more energy by incorrectly programming their heating controls, than if they had used manual alternatives. It seems that users are not 'in control' of their heating system in the way manufacturers intend, if they misunderstand how home heating systems contribute to their goals, and find it difficult to operate the heating controls.

To gain insights that could help specify the needs of an interface to support appropriate heating control, this paper looks to Norman's (1986) theory of the Gulf of Evaluation and Execution. Norman (1986) introduced the idea of the 'gulf of evaluation and execution' to explain why computer users did not operate systems in the way system designers intended. Norman emphasised that this problem specification applied equally to physical systems, directing the authors to consider home heating as a suitable domain for application. Norman approximates 7 stages of user

* Corresponding author.
E-mail address: Kmr1y14@soton.ac.uk (K.M.A. Revell).

http://dx.doi.org/10.1016/j.apergo.2016.03.005
0003-6870/

activity to describe how the user bridges the gulf. These stages take into account user goals, their perceptions, intentions and actions. Norman (1986) emphasised the need for user mental models to be compatible with the design model of the system to effectively bridge the gulf of evaluation and execution.

1.1. Norman's (1986) gulf of evaluation and execution

Norman's gulf of evaluation and execution represents the distance between a user's psychological goals (e.g. I want to be warm whilst watching TV with my spouse in the living room) and physical actions necessary, *with a specific system*, to achieve those goals (e.g. press the boiler override button on my programmer). This model shares similarities with Rasmussen's (1983) 'decision ladder' concept. According to Norman (1986), the user bridges these gulfs by going through a number of stages (Fig. 1). A user bridges the gulf of execution, by a) Forming their intention to use the system to achieve their goal, b) specifying the action sequence that will achieve their goal, and c) Executing the necessary actions with the input devices. They also need to bridge the gulf of evaluation by a) Perceiving the state of the system, b) Interpreting the state of the system so it can be compared to their goal, and c) Comparing the system state to their goal. Combined, with goal specification, these stages make up Norman's (1986) 7 stage model for user activity (illustrated in Fig. 1 within the home heating context).

Norman (1986) believes many systems can be characterised by how well they support the 7 stages of action and this approach has been adopted in the literature. Connell (1998) concluded that the gulf of execution and evaluation had advantages over analysis methods that considered taxonomies of error (e.g. Meister, 1997) or skills and rules (e.g. Reason, 1990). When performing error analysis on ticket vending machines, Connell (1998) found viewing erroneous button presses within the framework of the gulfs of evaluation and execution, more simply explained causes of error and pointed to practical design solutions. Cuomo and Bowen (1994) found analysis methods better addressed the stages that made up the gulfs of execution (intention, action specification, execution), than those responsible for the gulf of evaluation (perception, interpretation and evaluation), suggesting a gap in traditional

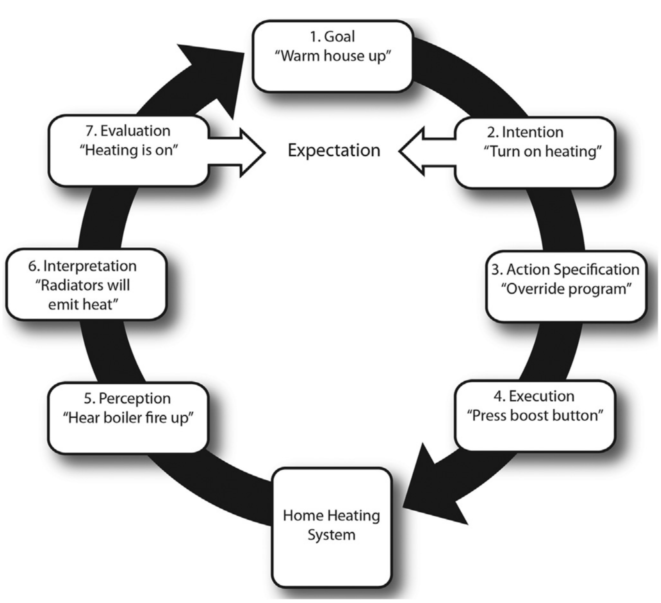

Fig. 1. Norman's (1986) Seven stages of user activity applied to home heating context. Stages 2–4 bridge the 'gulf of execution' and stages 5–7, bridge the 'gulf of evaluation'.

system evaluation. The gulfs of evaluation and execution has also been used to inform improvements to direct manipulation interaction (Hutchins et al., 1985; Kieras et al., 2001; Mohageg, 1991), understand difficulties in using programming languages (Ko et al., 2004; Edwards, 2005) and to facilitate human–robot interaction (Scholtz, 2002). Norman (1986) suggests that users will be more successful at achieving their goals when interacting with systems, if efforts are made to facilitate users at each of the 7 stages of activity. Norman's (1986) 7 stages of activity has not previously been applied to the home heating context, and the authors believe that by illustrating how users are expected to bridge these gulfs, insights into why people waste energy by inappropriate interaction will be identified. These insights could inform design or guidance requirements to support appropriate interaction for reducing wasted energy.

1.1.1. Conceptual and mental models of home heating systems

Mental models are internal constructs that are considered important in predicting, understanding and explaining human behaviour (Wickens, 1984; Kempton, 1986; Craik, 1943; Johnson-Laird, 1983) The notion has proved attractive when considering interface design (Carroll and Olson, 1987; Williges, 1987, Norman, 2002; Jenkins et al., 2010), to promote usability (Norman, 2002; Mack and Sharples, 2009; Jenkins et al., 2011), or enhance performance (Stanton and Young, 2000; Stanton and Baber, 2008; Grote et al., 2010; Bourbousson et al., 2011). The definition of mental models has been the topic of much debate over the last 20 years (Wilson and Rutherford, 1989; Bainbridge, 1992; Richardson and Ball, 2009 & Revell and Stanton, 2012).

In this paper, Norman's (1983) definition of mental models will be used. He distinguishes between user mental models, (UMMs) and Design models (DM). The UMM is defined as 'the actual mental model a user might have' gauged by observations or experimentation with the user (Norman, 1983). The DM is defined as a conceptualisation of the system held by the designer (Norman, 1986). For a fuller discussion of the distinction between these and other definitions of mental models, see Revell and Stanton (2012). For effective bridging of the gulfs, Norman (1986) demands the UMM is compatible with the DM of the underlying system. This can be achieved, either by bringing the user closer to the system (through experience, or training), or by bringing the system closer to the user through system design (Norman, 1986). Evidence of this approach has been offered by Staffon and Lindsay (1989) in the design of power plant processes, where provision of an interface containing a thermodynamic model of plant performance ensured operators had a compatible user mental model (CUMM) of the system states, before executing the controls. In the home heating context, the designer does not control the level of experience of the user, nor can they demand they undergo home heating training. Norman (1986) proposes that the designer can promote compatible user mental models through the choices they make when constructing the system image, which in turn influences user mental models (see Fig. 2).

Norman (1986) considered the DM & UMM as the 'scaffolding' for the bridges that enable users to cross the Gulfs of Evaluation and Execution. If this underlying structure is unsound, this impacts the 7 stages of activity, ultimately affecting the way users behave with, and interpret the system. The relationship between these two concepts is introduced separately by Norman (1986). The authors find merit in combining them in a single representation (see Fig. 3) to illustrate how the concepts are integrated. Norman (1986) explains that the scaffolding allows the user to derive possible courses of action and possible system responses. Norman (1986) emphasises that the DM should be accurate, consistent and complete, representation of the system, but importantly needs to relate to the