Conceptualising Processes of User Learning in Domestication Theory: What, why, and how?

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Abstract

The idea that users learn about new technologies in order to make them work within their daily lives is an important concept in domestication theory. It offers a way to conceptualise technology-user co-construction across household- and societal-level trajectories, and can be applied to identify policy relevant insights. However, while cognitive, symbolic and practical dimensions of learning in domestication are well established, processes of *how* users learn remain under-conceptualised. To address this gap, this paper employs process analysis to examine how users learned about a novel lower-carbon home heating technology (smart hybrid heat pumps). Starting from the principle that learning emerges from interactions between elements of technologies and of users' daily lives, it abductively develops a framework of four learning processes: *receiving, experiencing, interpreting* and *responding*. It illustrates how these four interlinked processes give rise to cognitive, symbolic and practical learning, then discusses their role in domestication trajectories and implications for policy.

Keywords*:* Domestication Theory, Users, Learning, Process Analysis, Smart Hybrid Heat Pumps

Introduction

Domestication theory offers important insights into possible outcomes when users encounter new technologies. It highlights that users do not passively consume technologies, but actively construct their meaning and use. This challenges technological determinism: the assumption that technology impact is inherent within technological artefacts. Users' routines and identities may also change through domesticating technologies. Conceptualising domestication as processes of *learning* about technologies illuminates how this co-construction of technologies and users develops over time and across multiple scales, including households and wider society (Sørensen, 1996, 2006).

Nonetheless, certain aspects of learning within domestication remain under-conceptualised. Emphasis has been placed on *why* learning happens: because users seek to make new technologies 'work', practically and symbolically, within their daily lives; and *what* types of learning occur. *Cognitive* learning involves users constructing understandings about what new technologies are for and how they work; *symbolic* learning involves the construction of meanings associated with technologies; and *practical* learning involves constructing routines of use in daily life (Sørensen et al., 2000; Sørensen, 2006). However, a general conceptualisation of *how* learning emerges has not been developed.

This paper responds to calls to further develop conceptualisations of learning processes in domestication theory (Juntunen, 2014) by addressing the question: taking domestication theory as a starting point, how can processes of user learning about a new end-use energy technology be conceptualised? The question is addressed through analysing user learning about an innovative energy efficient and smart automated home heating technology called smart hybrid heat pumps (SHHP) in the context of a technology trial. This paper presents findings of a process analysis (Pettigrew, 1997; Langley, 1999) based on repeat semi-structured interviews and observations with members of ten participating households. The analysis elaborates on the concept that cognitive, symbolic and practical learning emerge from interactions between technologies and users by identifying four interlinked learning processes, each of which emerges from interactions between elements of new technologies and users' daily lives:

- *Receiving* emerges from interactions between information that is available to users, and information that is important to users.
- *Experiencing* emerges from interactions between technology characteristics and users' routines and material arrangements.
- *Interpreting* emerges from interactions between information received and experiences, and meanings and understandings users hold.
- *Responding* emerges from interactions between meanings and understandings users hold, and strategies, actions and resources available to them.

The paper then discusses how this framework could inform actions aiming to influence learning processes in support of policy objectives, such as reducing greenhouse gas emissions from homes though the deployment of new end-use technologies (see also Sørensen, 2013).

The paper proceeds by outlining existing conceptualisations of learning in domestication theory, before detailing the methodological approach employed to develop these. It then presents empirical evidence to illustrate the four learning processes and their relationship to cognitive, symbolic and practical learning. The paper concludes by discussing contributions to conceptualisations of users' learning within domestication theory; policy implications; and opportunities for further work.

Conceptualisations of learning in domestication theory

Conceptualising domestication as learning

Domestication describes processes that occur as users seek to make technologies 'work' within their daily lives, expressing the idea that users must "tame" "wild" technologies so that they become meaningful, useful and familiar (Sørensen, 1996: 10, 2006: 45). Domestication theory originated in media and cultural studies, which highlighted that 'working' implies the creation of both routines of use and meanings, and defined four phases through which this occurs (Silverstone et al., 1992):

- Appropriation: acquiring technology
- Objectification: physically placing and displaying a technological artefact
- Incorporation: using technologies as part of the routines of daily life
- Conversion: using technologies in symbolic communication outside of the household

Domestication theory was developed within science and technology studies (STS) to bridge between two contrasting understandings of technology-user interaction. On the one hand, work on the social construction of technology (SCOT) highlighted technologies' *interpretive flexibility*, or the potential for technological artefacts to develop diverse meanings when appropriated by different user groups (Oudshoorn and Pinch, 2003). On the other hand, the concept of *technology script* highlighted how designers' ideas about expected or correct use are embodied within material features of technological artefacts, and enable or constrain use (Akrich, 1992). Influences such as social norms, advertising and authoritative voices may also act to script the "proper" use of technology (Bakardjieva, 2006:74).

Sørensen (1996) suggested that conceptualising domestication as a form of *social learning* – which emerges through interactions between groups, such as designers and users of artefacts – can bridge this apparent disconnect. The concept of user learning simultaneously illuminates how technologies contribute to the development of users' routines and identities, and how users contribute to create technologies' meanings and uses. Active learning, rather than passive reception of new technologies, occurs because users read and translate scripts to make technologies designed for ideal users 'work' in their own particular contexts (Akrich, 1992; Sørensen, 1996).

Building on the conceptualisation of domestication as learning and the four domestication phases, Sørensen, Aune and Hatling (2000) identified three more generic 'dimensions' of domestication processes. The *practical* dimension involves users' construction of patterns of use; the *symbolic* dimension involves the construction of meanings associated with technology, potentially including users' own identities; and the *cognitive* dimension involves learning about artefacts and appropriating knowledge. Each dimension involves cognitive processes (Sørensen, 2006), though it is important to remember that users learn as part of efforts to make new technologies "function and make sense" rather than to develop technically correct understandings (Sørensen et al., 2000, 240). The three dimensions can be understood as categories of learning occurring in domestication (Hargreaves et al., 2017; Parrish et al., 2021).

Current conceptualisations of learning within domestication theory and opportunities for conceptual development

There is longstanding interest in analysing processes of user learning during domestication. As Sørensen (1996: 3) explains,

> "What we want to achieve by studying social learning is to be able to highlight the temporal dimension of sociotechnical change, and thus to clarify the processes that may explain the particular features of a given trajectory of technological impacts."

Understanding the emergence of these impacts – including "the construction of new practices, of new needs, and new demands" Sørensen (1996: 4) – is highly relevant for policy. For example, the adoption and use of new technologies in the home has been associated with trajectories of increasing expectations of comfort, cleanliness and convenience, and associated environmental impacts via increased use of energy and other resources (Shove, 2003). Studying domestication as social learning holds the potential to examine the "microhistory" (Sørensen, 1996: 3) of the relationship between technology and culture through which such trajectories emerge. However, the processes through which users learn have remained conceptually underdeveloped.

The previous section indicates that current conceptualisations of learning in domestication theory identify why users learn about new technologies – to read and translate scripts and make new technologies 'work' as part of their daily lives – and what types of learning are involved – cognitive, symbolic and practical learning, at the level of households and wider society. A wide range of influences on processes of domestication have also been identified. As well as being influenced by technology and other forms of script, domestication involves users responding to the interests and needs of themselves and others, for example members of their household or wider social network (Sørensen, 1994, 2006; Bakardjieva, 2006). This can involve negotiation between household members with different interests and needs (Nyborg, 2015), which may also change throughout users' lives, for example with retirement or the arrival of children (Bakardjieva, 2006; Haddon, 2006; Juntunen, 2014).

Further influences are the range of *resources* users are able to draw upon. These include individuals' competences or skills (Sørensen, 1996), households' access to economic resources, which can influence technology acquisition and use (Bakardjieva, 2006), and existing material arrangements in the home that can impact on the incorporation of new technologies (Juntunen, 2014). Domestication can also be influenced by resources available at a societal level, such as infrastructures, technological alternatives, and socially circulating meanings (Sørensen, 1994, 2006). For example, the domestication of private cars is influenced by road and other infrastructures, the availability of alternatives such as public transport, and the range of socially circulating meanings associated with driving or not driving a car, such as ideas of individual freedom or environmental harm and protection (Sørensen, 2006). While diverse meanings may support diverse patterns of use or non-use, domestication may also be disciplined by social norms and expectations so that non-use requires considerable effort: for example, it may be difficult to resist conforming with socially dominant meanings that 'good' parenting requires driving a car to transport children (Sørensen, 2006).

Such resources may change over time. Users' past experiences and prior domestications can suggest strategies and actions for practical learning (Sørensen, 1994) and influence technology uptake and symbolic learning (Haddon, 2006), for example by increasing users' trust in a technology type (Juntunen, 2014). Prior domestication processes can also alter material arrangements in the home with implications for new technologies' adoption (Juntunen, 2014). Societal-level resources also change over time, including via collective household-level domestication processes, which can change social norms and influence marketing and design via market research and designers' ideas about users (Silverstone, 2006; Sørensen, 2006). The observation that outcomes of household-level domestication processes, and their emergent societal-level outcomes each influence "possibilities of learning new ways of doing and thinking" about technology (Sørensen, 2006: 56) have been conceptualised as domestication pathways (Juntunen, 2014) or trajectories (Sørensen, 2006).

Notwithstanding these contributions, *processes* illuminating how learning emerges during domestication remain under-conceptualised. Previously identified processes, such as learning-by-doing (Ryghaug and Toftaker, 2014; Hargreaves et al., 2017), learning-by-using (Juntunen, 2014) or learning by trial-and-error (Sørensen, 1996; Sørensen et al., 2000), do capture essential characteristics of users' learning about new technologies, namely, that learning occurs during use and is of a practical nature: seeking to make the technology 'work', rather than (necessarily) developing a technically correct understanding such as might be sought by consulting a users' manual or a qualified expert. The concept of trial-and-error also expresses the potential for users to learn about technologies creatively, developing approaches to learning that work within their daily lives. Nevertheless, these concepts remain rather abstract and do not support a detailed analysis of how and why learning about technology unfolds, including how this varies between different households. In a recently published handbook on domestication theory (Hartmann, 2023) this gap remains unaddressed.

The conceptual framework developed in this paper contributes to articulate how users' learning emerges through the interplay of different influences. Conceptualising of learning processes could help to inform policy by more closely relating influences on users' learning (such as peers, installers, or technology design) to outcomes of cognitive, symbolic or practical learning, in turn suggesting specific ways in which these outcomes might be influenced in support of policy objectives. In a previous study, I was able to show how policy-relevant outcomes emerged from users' learning about smart hybrid heat pumps and identified ways in which actors such as installers might influence these outcomes (Parrish et al., 2021). This paper builds on Parrish et al. (2021) by developing a generic framework of learning processes to support the application of a similar approach to other contexts and technology types.

Methodology

Overall approach: data collection and process analysis

Process analysis involves looking for patterns within temporally ordered data to answer questions about how and why change or stability may occur (Langley et al., 2013). In contrast with so-called variance approaches (such as regression analysis) which render time as simply a 'medium' in which pre-defined variables act on one another (Van De Ven and Poole, 2005), examining temporal progression enables interactions between elements to be studied, and emergent outcomes identified (Abbott, 1988, 2007). This makes process analysis well suited to analysing user learning within domestication theory.

Process analysis was applied to analyse semi-structured interviews and observations with ten households and two installers involved in the FREEDOM Project trial (Turvey et al., 2018) of smart hybrid heat pumps (SHHP). This UK government funded and industry led trial was conducted over the heating season of 2017-2018 with 75 households in Bridgend, South Wales. SHHP comprised electrically-driven air source heat pumps in combination with natural gas (fossil methane) fuelled boilers. This configuration was designed to enable the majority of space heating to be provided by the heat pump, while switching to the boiler during peak heat demand. Natural gas currently fuels most home heating in the UK, and it has been suggested that SHHP could help to avoid or defer the electricity network expansion required to support heat pump deployment (CCC, 2018, 2019).

Smart controls automated operation of SHHP, including switching between electricity and gas. App-based controls allowed users to input their desired temperature settings and timings for each day of the week, and remotely check and adjust heating using mobile devices. Wall-mounted thermostats also allowed temperatures to be checked and adjusted, though without changing the programmed schedule.

All interviewed households had 'wet' heating systems, where heated water is circulated through pipes to wall mounted radiators. The majority were connected to natural gas distribution networks, or 'mains gas', but two had boilers fuelled by relatively expensive liquid petroleum gas (LPG), delivered by road and stored in outdoor tanks. Most households in the UK have wet heating systems fuelled by mains gas, and often heat their homes solely in the morning and evening (Hanmer et al., 2019). However, unlike gas boilers, heat pumps operate more efficiently if they are run more constantly; in line with this, average heat pump peak electricity demand during the trial was measured at 04:00am and 14:30pm (Turvey et al., 2018). Domestic hot water was provided exclusively by the boiler element of SHHP and was available on demand, with app-based controls relating to space heating only. The analysis in this paper focusses on users' learning related to SHHP providing space heating, including use of controls, as these were more novel aspects of the technology.

To investigate users' learning about SHHP over time, semi-structured interviews were conducted with household users at two time points: initial interviews during or soon after technology installation, and follow-up interviews towards the end of the trial. Parrish et al. (2021) includes details of topic guides' content and their development. All user interviews took place in users' homes and included any adult household members who wished to take part. Following the trial, semi-structured interviews were conducted with the two installers responsible for setting up trial controls with the users; in six cases it was also possible to observe the final stage of installation, where installers explained trial equipment and set up controls with users. Processes of learning were identified primarily through analysis of user interviews, with analysis of installer interviews and observations employed to gain further insights into how these emerged.

14 households were interviewed in total. Of these, one declined a follow-up interview, while SHHP controls did not function as intended for another three. This paper analyses learning in the 10 remaining households. Table 1 summarises their composition, and indicates that many interviewees had occupations relating in some way to energy or technology, which may have influenced learning about SHHP. An overview of household composition is also presented as this may influence routines of using. As each household represents a case for the purposes of process analysis, this sample aligns with the recommendation to focus process analysis around careful comparison of a relatively small (6-10) number of cases (Pettigrew, 1997).

Steps in applying process analysis

Data analysis to conceptualise processes of user learning involved four main steps:

Table 1. Description of interviewed households

Interviewee(s) (all pseudonyms)	Household circumstances
Richard and Sophie	Working couple with a child at university. Richard teaches engineering at college while Sophie works for the local council.
Alan and Carol	Retired couple with adult children. Alan worked as a carpenter.
Anne and Cai	Retired couple with adult children. Cai worked as an electricity system engineer.
Jim and Rachel	Couple with adult children, one living at home. Jim works in the electricity sector while Rachel is often at home.
Ruth and Harry	Working couple. Ruth works for the local council while Harry is a toolmaker.
Clive	Couple with adult children, two living at home.
Hayley	Couple with three children. Hayley is a homemaker, her husband works as a carpenter.
Nick	Single man who works in a factory producing petrol engines.
Laura	Working couple with two children. Laura is a primary school teacher.
Paul	Working couple with children. Paul works in the electricity sector.

1. Themes of receiving, experiencing, interpreting and responding emerged though inductively coding user interviews, and process analysis was selected as an approach to abductively develop their conceptualisation.

Coding structures for initial and follow up user interviews were developed separately, and higher-level themes of receiving, experiencing, interpreting and responding emerged when these separate coding structures were merged (see Data Analysis A).

Rather than drawing on existing conceptualisations of learning in socio-technical systems (see, for example, van Mierlo and Beers, 2020), an abductive approach was chosen to remain firmly grounded in existing conceptualisations of learning in domestication theory, including giving equal weight to practical and symbolic as well as cognitive dimensions of learning. Drawing on existing notions of interactions between technologies and users, and households and wider society in domestication theory (Silverstone, 2006; Sørensen, 2006), the analysis sought to conceptualise users' learning as *emerging from interactions between elements associated with the new technology and with users' daily lives*. Process analysis supported this as it enables identification of processes through analysis of complex empirical data (Langley, 1999), and is well suited to study interactions (Abbott, 2007).

Analytical chronologies – temporally sequenced written data, "reaching towards theory presentation" by testing analytical vocabulary and identifying preliminary patterns and sequences (Pettigrew, 1997: 346) – were prepared to confirm the usefulness of the four themes before proceeding (see example in Data Analysis B).

2. *To structure process analysis, concepts of cognitive, symbolic and practical learning were used to identify outcomes of user learning.*

Process analysis is facilitated by identifying defined "outcomes" in the data, then seeking explanations about how these arose (Pettigrew, 1997: 342-344). To do this, the established concepts of cognitive, symbolic and practical learning in domestication were operationalised as follows:

- Cognitive: understandings related to what SHHP does and how it works.
- Symbolic: meanings related to feelings that users communicated about SHHP or symbolic understandings. Symbolic understandings were differentiated from cognitive understandings based on a judgement of whether the user could explain why they held the idea (irrespective of whether the explanation was technically correct).
- Practical: routines of interacting with SHHP controls and of using heat (such as using

heating to dry laundry or care for children, or using different approaches to create thermal comfort).

These outcomes do not denote any final result of domestication, but understandings, meanings and uses observed at particular moments in time.

3. Three temporal periods were defined to further structure process analysis.

Defining temporal periods is a common way to structure process analysis. It enables conceptual ideas to be replicated in successive time periods and helps to analyse how processes progress and interact over time (Pettigrew, 1997; Langley, 1999; Langley et al., 2013). The domestication phases discussed above cannot fulfil this function as they do not follow a temporal progression. Instead, three temporal periods were identified based on "discontinuities" observed in the empirical data (Langley et al., 2013: 7):

1. *Uptake/installation:* the time period over which interviewees decided to become involved in the trial and had the SHHP installed in their homes; relates primarily to technology adoption rather than use.
2. *Early use:* characterised by an initial period of adjusting control settings (often referred to by interviewees as "tweaking" or "playing" with settings) and forming initial routines of using SHHP.
3. *Later use:* this temporal period simply follows early use and extends until the end of the period of analysis. It had different characteristics in different households: for example, in some households, routines created in early use remained largely undisturbed throughout later use, while in others these changed following a period of cold weather.

4. Using these two structuring devices, influences on learning outcomes were identified for separate households, then categorised into generic elements interacting in learning processes.

Influences on cognitive, symbolic and practical learning about SHHP across the three temporal periods were identified for each household separately (see example in Data Analysis C).

The synthesis of these influences into generic elements was supported by creating visualisations: an approach used in process analysis to move towards greater generalisation and abstraction (Langley, 1999). Visualisations were sketched by hand and developed iteratively, responding to questions and insights arising with each iteration (see examples in Data Analysis D). Constructing visualisations forced synthesis into generic elements able to capture a range of specific influences on learning. As visualisations were structured across the three temporal periods, their construction also supported longitudinal replication and testing (Langley et al., 2013) of learning process' conceptualisation.

Conceptualising users' learning about smart hybrid heat pumps in the FREEDOM Project trial

This section identifies four interlinked processes through which users learn about new technologies during domestication: *receiving*, *experiencing*, *interpreting* and *responding*. Each process emerges from interactions between two elements, which relate to different aspects of the technology and of users' daily lives. The section is structured around the temporal periods of uptake and installation, early use, and later use to illustrate how analysis across these three temporal periods enabled conceptualisations of the learning processes to be developed, tested and refined. Finally, the conceptualisation of learning processes based on this analysis are summarised: Table 2 summarises the interacting elements involved in each learning process, while Figure 1 summarises interlinkages between the four learning processes, and their relationship to outcomes of cognitive, symbolic and practical learning.

Uptake and installation: conceptualising processes of receiving and interpreting

Across all interviewed households, users' learning during the period of uptake and installation mainly involved constructing understandings and meanings about SHHP (cognitive and symbolic learning). This involved the processes of users *receiving* information, and *interpreting* this information by drawing on meanings and understandings they already held.

Receiving

The process of receiving information varied between users according to their needs and interests. For example, some interviewees explained that they focussed on receiving practical information about the controls, and paid less attention to more technical details:

> A new sort of system on the market, that - with a heat pump. I didn't understand any of that.
>
> Everything he [installer] said to me really was just more - I was in a rush as it is, right, app is on here, OK. (Nick, initial interview)

Other users actively sought information to learn about elements of the technology that are important to them. This could involve questioning installers, online research or consulting social networks. For example, Jim (initial interview) explained that "That's why I went on the internet, to look at it… I like electronics." Hayley (initial interview) explained that "My husband's in the trade, he was asking different people […] to see if they thought it was suitable", and Laura used online research to gain reassurance about the legitimacy of the trial itself:

> So often you get people trying to push solar panels, and this and that, and you think what is your motive? Because there are a lot of schemes, aren't there, that seem too good to be true, and I did wonder. But yeah, I read up and realised that it's actually a bona fide trial! (Laura, initial interview)

These quotes illustrate how users' needs and interests influence their attention to information that is presented to them, for example by installers, as well as decisions to seek additional information about new technologies. Thus, the process of *receiving* information can be conceptualised as emerging from the interaction between the *information available to users* and *information important to users* as they seek to make new technologies 'work'.

It is important to note that this way of thinking about users receiving information does not imply falling back on ideas about passive users and 'information deficit' models (e.g. Simis et al., 2016). Users are active when they direct their attention to different parts of the information provided to them, for example by technology installers and written materials provided about the technology. Empirical data presented across the empirical analysis in this paper illustrates how users also actively sought additional information: from installers, members of their social networks, the internet, and in one case a fellow triallist who made contact after seeing the heat pump unit installed on the outside of a house. In either case, users decide what information is important to them, guided by their needs and interests.

Interpreting

To construct understandings and meanings about SHHP, users drew on existing understandings and meanings that they associated with information received about the new technology. For example, a previous analysis of this data identified that many interviewees constructed the cognitive misconception that heat pumps cannot provide space heating at lower outdoor temperatures. This may have resulted from users interpreting the information that heat pumps are less *efficient* at lower outdoor temperatures, provided by installers, to construct the understanding that they are not *effective* at these temperatures (Parrish et al. 2021). This illustrates how the construction of understandings (cognitive learning) may be influenced by users' existing understandings of technical language.

When constructing meanings (symbolic learning), interviewees often associated SHHP with experiences of or ideas about "smart" technology and app-based controls more generally. For example, Harry (follow-up interview) related the SHHP controls to technologies he already used, including online banking and his car notifying him of low tyre pressure, and concluded "everything's smart now, so why wouldn't your heating be?". Meanwhile, Hayley (initial interview) made sense of new smart heating controls that she found "a bit scary" with the reflection that "that's the way technology is going, though, isn't it? With everything."

These quotes illustrate how processes of *interpreting* emerge from interactions between *information received* and *meanings and understandings* users already hold: including cognitive understandings of technical language, meanings derived from users' prior experiences of technologies they associate with the new technology, or ideas about technological progress more generally. They indicate how cognitive and symbolic learning emerge through interlinked processes of receiving and interpreting. The following sub-section further develops the conceptualisation of interpreting by illustrating how users may interpret their *experiences* of technology, as well as information received.

Early use: conceptualising processes of experiencing, interpreting and responding

This temporal phase involved users developing routines of using the new technology (practical learning). This sub-section illustrates how this practical learning emerged from processes of users *experiencing* the SHHP system, *interpreting,* and *responding* to their experiences.

Experiencing

Users' experiences of SHHP formed an important part of developing routines of use. These varied between households due to interactions between *characteristics of the technology* and users' existing *routines and material arrangements*.

For example, night-time heating was characteristic of SHHP because heat pump efficiency generally increases with more constant operation. This differed from interviewees' previous routines of using heat. However, although many interviewees described experiencing warmer temperatures during the night-time, this was not the case for Richard and Sophie: they "always have the [bedroom] window open, because fresh air's good for you" (Richard and Sophie, initial interview). Clive similarly did not experience night-time heating. He explained that "we just like a cold bedroom. Window is never closed" and that he does not have a radiator installed in his master bedroom:

> When I was young we used to go down to my Auntie's farm…. I always remember going in the bedroom one evening, and the snow was coming in the windows, and she had about that much, the old-fashioned blankets, sheets and quilts, and eiderdowns as they called them, that thick, and I know where she's coming from now… So we don't have a radiator in there. (Clive, initial interview)

These quotes illustrate how processes of experiencing heating varied due to users' existing routines of opening windows, and material arrangements of radiator installation. Similarly, more constant day-time heating provided by SHHP was only experienced by interviewees whose existing routines meant they were sometimes at home during the day.

Experiences of SHHP controls also varied due to users' prior routines of using apps and mobile devices. For example, Alan (follow-up interview) explained that "I've only got a clockwork phone, anyway. The others do my head in". Consequently, he experienced the wall-mounted thermostat as easier to use than the app-based controls:

> If you're just walking by [the thermostat], saves getting the iPad out or whatever you call it. Saves getting that out and switching it on. (Alan, follow-up interview)

Conversely, users with existing routines of using smartphones and apps experienced the app-based controls as easier to use, and even "addictive":

> Before if it got a little bit too hot, and I was lazy just laying on the settee thinking I can't be arsed to get up and touch the thermostat, I'd leave it. At least with my phone it's just right next to me. I'll check the app, what it is, and just turn it down a little touch. So I manage it a lot more now, on the app, than I would before. (Nick, initial interview)

> You do find it addictive! I do, I get into work sometimes in the morning, and I check my Facebook, and I check [...] WhatsApp, and then I usually see what the heating's doing. (Harry, initial interview)

These quotes illustrate how processes of *experiencing* emerge from *interactions between technology characteristics* (such as more constant heating and designed features of controls) and *users' routines and material arrangements* (including the location of radiators, and routines of time spent in the home, opening windows, and using apps and mobile devices). The following sub-section illustrates how differing patterns of practical learning suggest processes of experiencing may be followed by processes of *interpreting* and *respond-*

ing as users endeavour to make new technologies 'work'.

Interpreting

Building on the previous section, this sub-section further conceptualises the process of *interpreting* by illustrating how users interpret their *experiences*, as well as information they receive. While users sometimes acted to change their experiences of heating from SHHP to fit their existing routines, they also changed some routines to fit novel experiences; these contrasting patterns of practical learning can be understood to follow users *interpreting* which of their experiences represent SHHP 'working'.

During early use, most interviewees adjusted SHHP control settings to make experiences of heating by SHHP better fit their existing routines. For example, Hayley adjusted the heating schedule to better fit her routines of caring for her family:

> We were putting it to come on a little bit earlier, so it was warm for when the children come home from school. (Hayley, follow-up interview)

Other households changed control settings with the aim of avoiding or reducing night-time heating which they experienced as uncomfortably warm. For example, Anne (initial interview) commented that "I nearly melted away last night... so I've turned the radiator in the bedroom just about off today". Similarly, Alan (follow-up interview) explained that "We don't like it too warm in the nights", and interpreted the experience of night-time heating as surprising and unwelcome:

> In the beginning, you wake up in the night and think good God, it's warm here! You're throwing your duvet off. (Alan, follow-up interview)

By contrast, households who experienced more constant day-time heating all changed their routines to fit this novel experience. For example, Alan (initial interview) explained that with their former heating system "Because we're busy people we don't tend to have it on a lot in the day". However, he explained that with the new SHHP:

> I think the system is great, because the house is never cold. You know, sometimes you're out, and you come in and think, Oh, God! So you turn the heating up, and then you've got to sit there for half an hour with your coat on, you know what I mean? So I think the system is great in that respect, 'cause you come in, you can take your coat off straight away because it's not uncomfortable. (Alan, follow-up interview)

Interpreting experiences can thus result in constructing specific meanings of SHHP technology (symbolic learning), such as that "the system is great", alongside influencing practical learning.

Responding

The process of *responding* helps to understand the actions users take after interpreting their experiences. This sub-section illustrates how the process of responding emerges from interactions between *meanings and understandings* users construct about technology and *actions and resources* they can access and use.

After his living room temperatures rose following installation of the SHHP thermostat, Clive adjusted his thermostat settings based on the new SHHP thermostat being located in his hallway, rather than living room. He explained how understanding thermostat operation informed this response:

> A thermostat in a hallway is not the ideal place to put it. Usually it should go in your living area. And from my point of view, my hallway is always colder than everywhere else. So I brought it down here into the lounge, but found that it lost signal […] So I had to put it back into the hallway […] what I've had to do is reduce the temperature on that thermostat to compensate for it being colder out there, and giving me the ideal temperature in here. (Clive, follow-up interview)

Similarly, Alan explained how an understanding he constructed during the trial, that more constant heating is more efficient, meant he responded to experiences of night-time heating by turning down thermostatic valves (TRVs) on his bedroom radiators rather than reducing the night-time temperature setting in the app:

> I think you're defeating what you're trying to do then, aren't you? You're warming up from nearly zero, then, up to where you want it. So it's back to the old system, then, before they put this in. (Alan, follow-up interview)

These quotes illustrate that processes of responding can involve pre-existing or newly constructed *understandings* related to new technologies, together with access to *resources* such as TRVs, and repertoires of appropriate *actions*, such as adjusting thermostat control settings.

Meanings can also form part of processes of responding. The previous sub-section introduced the idea that processes of responding arise from users interpreting their experiences as SHHP 'working' or not working. Meanings constructed through interpreting information received about SHHP can also inform responding. For example, Paul explained that constructing meanings of SHHP as a more "efficient" and "economic" system (Paul, initial interview) contributed to his household increasing their use of heat compared to their former LPG-fuelled boiler. These meanings enabled Paul to respond in line with socially circulating meanings that 'proper' modern heating involves heating multiple rooms in the house: he described the SHHP as a "truly usable system" (Paul, follow-up interview) because it allowed them to depart from their previous "olden days" routines:

> We'd all have huddled around here [in the living room] as a family, which is a nice thing, don't get me wrong, it's back to the olden days I suppose, everyone had an open fireplace, but now that we've got rooms that are more comfortable to be in, the kids tend to go up to their own rooms now, my wife will spend more time out in the kitchen. (Paul, follow-up interview)

This illustrates how processes of responding give rise to practical learning. The following sub-section further develops the conceptualisation of responding, by illustrating how different *strategies* adopted by users form part of the interacting elements involved in this process.

Later use: further conceptualising processes of experiencing and responding

This temporal period extends from the time after households created initial routines of using SHHP (early use) to the end of the period of analysis. In later use, different households exhibited sometimes markedly different patterns of learning. Analysing learning in later use enabled processes of *experiencing* and *responding* to be further conceptualised, through applying concepts developed when analysing early use, and elaborating on these as necessary to explain new empirical observations.

Experiencing

Interviewees' accounts in later use suggest that experiences of technology can change over time. For example, with accumulated experience many interviewees stopped frequently checking or adjusting control settings in the SHHP app. Sophie initially remarked "I don't know how many times I've looked at it today - I've been showing people!" (Sophie, initial interview), but later described how:

> I don't look at the app any more…three or four weeks?... That was probably about it, and then I lost interest in it. (Sophie, follow-up interview)

Sophie explained this change occurred because the information available in the app is "the same thing every day" (Sophie, follow-up interview). This suggests that her experiences of the app changed due to her initial routine of regular checking, together with the technology's characteristics. Consequently, she re-interpreted the app as uninteresting and responded by changing her routines. This replicates analysis in the temporal phase of early use by illustrating how interlinked processes of experiencing, interpreting and responding give rise to practical learning. It also highlights that processes of experiencing involve routines constructed in the course of domesticating a new technology, as well as users' prior routines.

Responding

The role users' *strategies* can play in processes of responding was demonstrated by two households experiencing similar issues with their heating and drawing on contrasting strategies to respond, with marked differences in learning as a result.

Both Hayley and Harry began to experience low room temperatures during a period of particularly cold weather. Their accounts, and observations of their installer working in other households, suggest this was because the flow temperature of the gas boiler component of the SHHP was initially set to 50^{0}C (a relatively low setting) to increase efficiency. Hayley responded through the strategy of immediately asking for expert help:

> We were turning it up… when we had the cold spell, but the room temperature was going up to 18[°C], it wouldn't go any higher. So [husband] spoke to [installer], and he explained we had to go upstairs and do something on the boiler, which [husband] done, so the room temperature could come up. So that's all done now. (Hayley, follow-up interview)

This enabled the household to change their experiences of SHHP relatively quickly, and they did not interpret their experiences, or information they received, to construct new understandings, meanings, or routines of use:

> We don't know why, but for some reason the room temperature wasn't going up over 18. (Hayley, follow-up interview)

Hayley's account also illustrates how processes of *responding* and *receiving* can be linked if users seek additional information (for example, checking room temperatures or asking installers) as part of the process of responding. Applying the concepts of interpreting and responding to Laura's quote presented in the temporal phase uptake and installation reveals that similar processes occurred during uptake: after Laura drew on existing meanings about "people trying to push solar panels" to construct the meaning that the trial may be "too good to be true", she responded by seeking additional information in order to conclude that "it's actually a bona fide trial!". Like other forms of responding, processes of receiving are influenced by the resources available to users as well as the strategies and actions they draw upon. For example, Laura was able to seek information online because she had internet access and could conduct this kind of research, while in the temporal phase uptake and installation Hayley describes how her husband was able to seek informal advice from tradespeople who were members of his social network.

Like Hayley, Ruth and Harry experienced a period of uncomfortably low evening temperatures, and found that changing control settings did not have the expected effect:

> Ruth would say to me, it's a bit cold, turn the heating up… So I said right, I'll turn it up, to 25[°C]. And I'd sit there, and I'd think, nothing's happening. It doesn't seem to be getting any warmer. Whereas before, when we had just the gas, you'd turn it up, and the boiler would kick in, and whoomph, it would ramp up. (Harry, follow-up interview)

Unlike Hayley, Harry adopted a strategy of trial-and-error to respond to this experience, experimenting with a range of adjustments to control settings over a couple of weeks. This included *actions* drawn from previous learning about technologies Harry associated with SHHP; for example, he described how:

> I went and turned it off and turned it back on again. Because to me, that's always the issue, isn't it, with electronics? (Harry, follow-up interview)

Harry also began interpreting his experiences of SHHP in ways that influenced the actions he took when responding. This was initiated by an interaction with another triallist who knocked on his door:

> He said, I've noticed you've got the heat exchanger outside… and he said, I've had it installed in my house…. and he was convinced [laughing]… he said, I'm sure they're turning it down. (Harry, follow-up interview)

While Harry was initially dismissive, over time he found that "it made me think, then, because we were having these little issues" (Harry, follow-up interview). He began to re-interpret the SHHP smart controls, including through comparison with familiar technologies, and wondered whether they involved remote control in pursuit of certain objectives:

> There's not a laptop downstairs running my heating system, is there? There's just a box, and I'm thinking, really? Can't be that clever. Unless it's being done remotely.
>
> I don't know if it wasn't explained really well, but because we've got this heat exchanger, so I assume that because that uses less energy it [SHHP system] decides, I'll use that more than the gas. (Harry, follow-up interview)

This new understanding of the SHHP controls led Harry to increase temperature settings and extend the timing of the main heating periods programmed via the app, to try to counteract the controls "trying to do it so efficiently" (Harry, follow-up interview). This included raising the boiler flow temperature. However, following a strategy of trial-and-error initiated a series of learning processes that led to practical, and potentially cognitive and symbolic learning. Harry ultimately responded to his experiences by changing his routines of heating in long-lasting ways (at follow-up interview, a warm spring day, his room temperature setting remained at 23°C, compared to 19°C at initial interview). He also began to re-interpret how the SHHP operated and under whose control.

Summary of learning processes

The preceding analysis illustrated how users learn about new technologies via processes of receiving, experiencing, interpreting and responding, which emerge from interactions between elements of new technologies and elements of users' daily lives. These interacting elements are summarised in Table 2. The analysis also illustrates how the four learning processes may be interlinked, with sequences of learning processes resulting in cognitive, symbolic and practical learning. Figure 1 provides an overview of these links. Cognitive and symbolic learning emerge from interlinked processes of users *receiving* information or *experiencing* different aspects of new technologies, then *interpreting* information and experiences to construct new understandings and meanings. Practical learning emerges from interlinked processes of *interpreting* whether experiences represent technology 'working' and *responding* accordingly. Processes of responding link back to processes of *receiving* when they involve users seeking additional information, and to processes of *experiencing* when users' actions (such as changing control settings) change their experiences of technology.

It is important to note that Figure 1 provides only an abstract summary of the relationship between the four learning processes and the three types of learning outcomes. In practice, the links between learning processes and outcomes may vary in different households and at different times. For example, returning to the empirical analysis in the temporal period later use illustrates that experiencing may not be followed by cognitive, symbolic, or practical learning if, as in Hayley's case, this is not necessary for users to make the technology work; responding may not result in practical learning if it involves one-off actions as part of a strategy of trial-and-error; and, as in Harry's case, users may pass through multiple rounds of learning processes (from responding back through receiving/experiencing) as part of a single endeavour to make technology 'work'. This reiterates that users learn pragmatically as part of seeking to make new technologies 'work', practically and symbolically, rather than to develop 'correct' knowledge or understanding, and that the outcomes of any particular domestication process remains an empirical question. The following section discusses the conceptual contribution represented by this novel framework and its wider implications.

Table 2. Four processes of user learning, emerging from interactions between elements of the technology and of users' daily lives.

PROCESS	INTERACTING ELEMENTS	
RECEIVING	Information available to users	Information important to users
EXPERIENCING	Technology characteristics	Routines & material arrangements
INTERPRETING	Information received & experiences	Meanings & understandings
RESPONDING	Meanings & understandings	Strategies, actions & resources

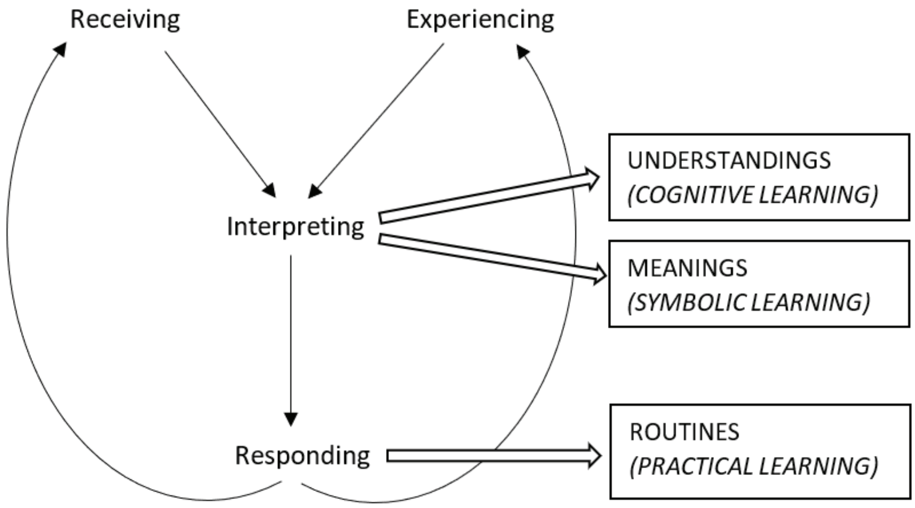

Figure 1. Links between the four learning processes and their relationship to cognitive, symbolic and practical learning. The figure illustrates overall relationships, which may unfold differently in different households and different moments in time.

Discussion and conclusions

Through a process analysis of users' learning about smart hybrid heat pumps (SHHP), this paper develops a novel framework of four interlinked learning processes that articulates how users' learning emerges during technology domestication. This section positions this contribution in relation to existing conceptualisations of users' learning in domestication theory, showing how it builds upon and develops them. It then discusses how the novel framework could advance the potential for domestication theory to inform policy making, and identifies opportunities for further work.

Conceptual development

The framework developed in this paper offers an approach to understand how cognitive, symbolic, and practical learning about new technologies emerge from interactions between elements of the technology and of users' daily lives. This conceptual approach is grounded in existing conceptualisations of interactions in domestication processes, including users' negotiations with technology script, and societal-level elements such as social norms (see, for example, Silverstone, 2006; Sørensen, 2006). However, it goes beyond these by defining *how* cognitive, symbolic and practical learning emerge though specific interactions between defined elements. This addresses calls to further conceptualise learning processes within domestication theory (Juntunen, 2014).

The framework of learning processes builds on previous work on learning in domestication theory. By identifying that much learning takes place during technology use, it re-emphasises the importance of learning-by-doing in domestication (Ryghaug and Toftaker, 2014; Hargreaves et al., 2017), but develops conceptualisations of concrete learning processes happening within this. It also encompasses the potential for trial-and-error (Sørensen, 1996; Sørensen et al., 2000) to form an important part of users' learning. However, it identifies this as one of a range of possible 'strategies' that users might adopt, and highlights that different strategies can have important implications for learning outcomes. Similarly, the framework's definition of interacting elements builds on and supports previous work identifying various influences on users' learning: for example, the element 'information important to users' can be considered as one aspect of users' needs and interests, which are conceptualised as a central influence on domestication (see, for example, Sørensen, 1996, 2006); 'information available to users' may include information from advertising and authoritative voices, previously identified in analyses such as Bakardjieva (2006) as influences on user learning; while the potential for 'existing material arrangements' and 'existing routines' to influence the domestication of new technologies has been demonstrated by analyses such as Juntunen (2014) and Judson et al. (2015). However, because the framework defines generic elements, it should be applicable to analyse users' learning about other technologies in other contexts. Defining interacting elements also offers a systematic approach to more comprehensively analyse users' learning, which can draw attention to important but less striking aspects of this. For example, while changes in routines can stand out as examples of practical learning, stability in routines is another form of practical learning, which involves continuing to interpret certain experiences as technology 'working', and responding by maintaining those routines. This invites us to consider how and why domestication processes result in change in some routines alongside stability in others, and what informs users' ideas about which experiences constitute technology 'working'.

Temporality is a key dimension of social learning, including learning during domestication (Sørensen, 1996). While the framework of four learning processes does not include an explicit time dimension, the temporal dimension of social learning is captured when outcome(s) of one process become element(s) interacting in subsequent processes. Figure 2 visualises how the framework can help to illuminate the emergence of such domestication pathways (Juntunen, 2014) at the household level. Users' accounts presented in this article illustrate, for example, how processes of interpreting SHHP involved meanings developed through prior domestications of related technologies, such as technologies users identify as 'smart'; that experiencing SHHP was strongly influenced by routines of use constructed through prior domestications of gas boilers and mobile devices; and that processes of responding can be informed by understandings of controls, such as thermostats and thermostatic radiator valves, also constructed during the domestication of gas boilers. This builds on previous work identifying how prior domestications may influence technology uptake and symbolic learning (Haddon, 2006); that the domestication of new technologies is influenced by previously constructed routines of use (see, for example, Sørensen, 1994; Judson et al., 2015; Nyborg, 2015); and that prior domestications can suggest strategies and actions for practical learning (Sørensen, 1994).

The framework can also help to illuminate societal domestication trajectories, which emerge through reciprocal relationships between household-level domestication processes and societal-level influences on these, such as social norms or large-scale material infrastructures (Sørensen, 2006). Figure 3 illustrates how the framework can illuminate reciprocal relationships between household domestication processes and socially circulating meanings. It visualises how socially circulating meanings – such as Paul's account of meanings relating to 'proper', modern heating – can influence the construction of routines via processes of interpreting which experiences represent technology 'working', and responding accordingly. This could result in the construction of new routines, such as Paul's account of his family spending more time in newly-heated rooms. It could also reinforce existing routines. This practical learning is accompanied by symbolic learning, such as Alan's description of more constant daytime heating as 'great', and collective symbolic learning can influence socially circulating meanings and subsequent household-level domestications.

Previous work on domestication has shown that initially novel or luxurious experiences can come to be normalised and taken for granted over time (Pantzar, 2023), and the adoption and use of new technologies has been associated with trajectories of increasing expectations of comfort, cleanliness and convenience (Shove, 2003). By supporting investigation of relationships between household domestication processes and societal-level elements such as social norms, processes of experiencing, interpreting and responding may help to illuminate one aspect of the "ratchet-like" (Shove, 2003: 399) mechanism underlying this. Given the environmental impacts of associated resource use, this also has implications for policy.

Policy implications

Identifying actions that could influence users' learning in support of policy objectives is an important implication of conceptualising processes of user learning. In a previous study (Parrish et al. 2021), I identified that users constructed the technical misconception that heat pumps are ineffective at lower outdoor temperatures (cognitive learning), which counters policy expectations that learning about heat pumps through using a hybrid system will support future acceptance of stand-alone heat pumps (CCC, 2018, 2019, 2023). Finding that this misconception likely arose through the ways users interpreted information provided to them by installers enabled me to suggest it could be avoided by using non-technical language. Similarly, in this previous study I suggested that ensuring SHHP users have access to thermostatic radiator valves on bedroom radiators, and know how to use them, could help to avoid experiencing uncomfortably warm night-time temperatures, and unintended uses of SHHP (practical learning) that may emerge as a result.

The generic framework of learning processes developed in this paper should support similar analyses of user learning and identification of policy implications related to other technologies and contexts. If observed understandings, meanings, or uses of a new technology are identified as relevant for policy, the framework can help to trace back through the processes and interacting element though which they emerged, and identify specific ways in which these could be changed. As an example, cognitive learning could be influenced by paying attention to processes of *receiving* and *interpreting* information, and the interacting elements through which they emerge: *information available to users*, *information important to users*, and *understandings and meanings users already hold*. As well as avoiding technical language, general policy implications include seeking to provide information that is relevant and accessible to users, for example by relating it to users' needs and interests, providing it verbally as well as in writing, and providing a channel to seek expert advice over a period of time, as changing experiences mean new forms of information may become relevant (see also Parrish et al., 2021). It could also be helpful to support other means for users to access information, including peer-to-peer learning (Judson et al., 2015). For some users, online forums can be well suited to support peer-to-peer learning: reducing uncertainty, helping users to adapt new technologies to local contexts, and increasing their social legitimacy. As they are not limited to particular spatial scales, they can include large numbers of users and accommodate sub-groups that support diverse user needs (Hyysalo, 2021). They can help users to form relationships with 'warm experts' (Bakardjieva, 2005), which could be important if their immediate social networks do not have knowledge of particular new technologies (c.f. Hargreaves et al., 2017). Empirical data presented in this paper also highlights the potential for peer-to-peer learning to disseminate misconceptions. The potential for moderation could be another benefit of online forums if it helps to avoid this. However, excessive moderation of forums may reduce the potential for user learning (Hyysalo, 2021), so care should be taken to balance these concerns. As a second example, practical learning could be influenced by paying attention to processes of *experiencing*, *interpreting* and *responding*, and the interacting elements through which they emerge: *technology characteristics*, *routines and material arrangements*, *understandings and meanings users already hold*, and *strategies, actions and resources* available to respond. By helping to identify specific policy actions, this work builds on previous studies suggesting influences on users' learning, including technology design, installers, or users' peers could be policy targets, without identifying how these might be changed (see, for example, Hargreaves et al., 2017; Judson et al., 2015). Of course, this is not intended to suggest that it is possible to influence users' learning in a deterministic way: as the outcome of domestication processes is always an empirical question (Sørensen, 2006), making policy informed by domestication theory would also imply adopting more reflexive policy practices. This is discussed further by Sørensen (2013) and Jensen et al. (2019).

Illuminating processes involved in societal domestication trajectories also has relevance for decarbonisation policy. Trajectories of increasing service demand accompanying the adoption of new technologies (Shove, 2003) may jeopardise efforts to address climate change, even alongside increases in technical efficiency (Darby and Fawcett, 2018; Labanca and Bertoldi, 2018; Shove, 2018). The analysis presented in this paper shows how socially circulating meanings about the normal or desirable performance of technologies, or expectations about technological development, can influence users' learning. It also suggests how the emergence or reproduction of social norms through collective household domestication processes could contribute to societal domestication trajectories. The potential to illuminate processes by which social norms emerge is an important feature of domestication theory, particularly as such processes are not typically considered in policy making (Shove, 2010).

Opportunities for further work

Further work could apply the framework to further investigate the interrelationship between users' learning about new technologies and societal trajectories of escalating demand for energy services, with the aim of identifying how these might be disrupted.

It would also be helpful to test the framework of learning processes by applying it to analyse learning about other technologies in other contexts. Expanding the empirical sample to include non-users could test the processes of receiving and interpreting information, while involving a higher number of household members in data collection could illuminate how learning processes interact with the negotiation of needs and interests within households. The framework of learning processes should also be tested through application to other technology types: as an example of a more efficient and automated technology, SHHP were designed to substitute for a technology (gas boilers) which users had previously domesticated, and to perform emissions reductions without requiring active input from users (Stumpf et al., 2018). Furthermore, users' learning is likely to differ in contexts other than technology trials, for example in peer-to-peer learning, so the applicability of the framework in diverse contexts should be assessed.

As it stands, the framework of learning processes developed in this paper advances conceptualisations of users' learning in domestication theory by illuminating *how* users learn about new technologies, and relating this to existing conceptualisations of what users learn and why. This also contributes to efforts to apply domestication theory to derive policy recommendations, by helping to identify how specific actions could influence learning outcomes.

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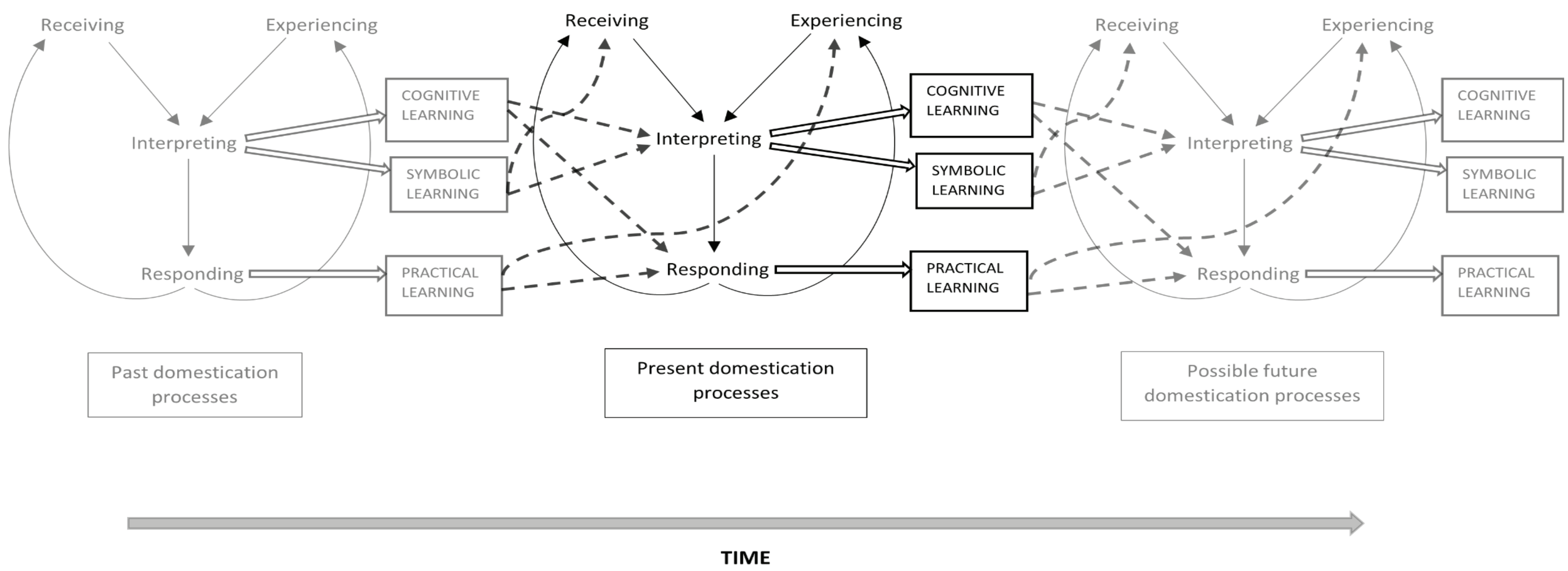

Figure 2. Visualising interactions between learning processes and household domestication trajectories. Dashed arrows indicate how cognitive, symbolic and practical learning give rise to elements interacting in learning processes during later domestications. For example, understandings and meanings constructed through cognitive and symbolic learning influence processes of interpreting if they interact with information received and experiences of new technologies. Meanings constructed through symbolic learning may influence processes of receiving if they influence what information is important to users, and routines constructed through practical learning influence experiencing if they interact with the characteristics of new technologies. Strategies and actions of responding may be influenced by previous cognitive learning, for example understandings of how to use controls, and practical learning in the form of practical know-how or routines of responding to common experiences.

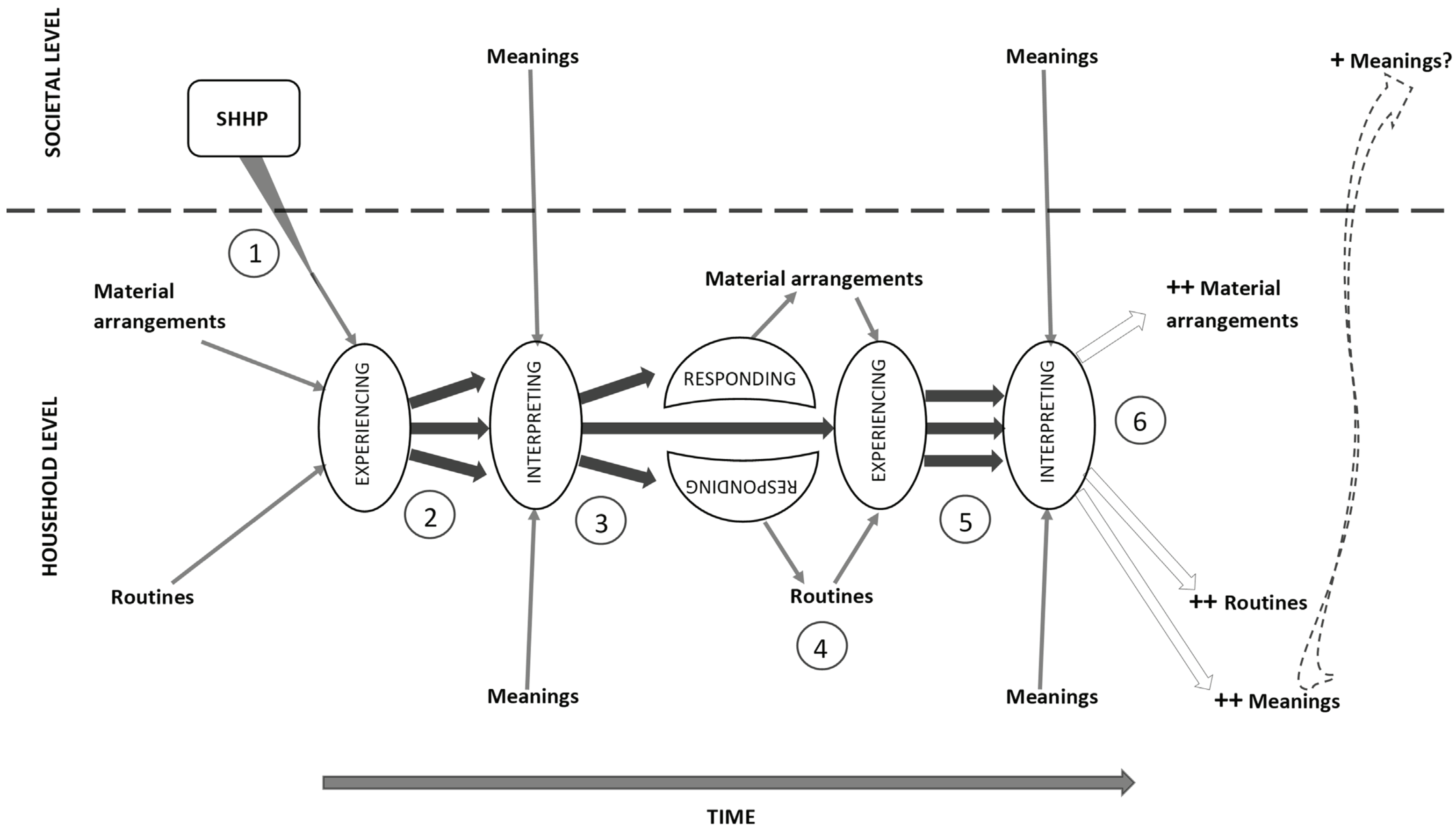

Figure 3. Visualising relationships between learning processes at the household level, and socially circulating meanings of what constitutes 'working'
1) SHHP becomes part of household material arrangements through uptake and installation. 2) Processes of experiencing different SHHP characteristics emerge from their interaction with pre-existing household routines and material arrangements. 3) Processes of interpreting whether or not different experiences constitute 'working' emerge from their interaction with meanings of 'working' constructed through previous household-level domestications, and/or those circulating at the societal level. 4) Processes of responding may change routines and/or material arrangements as users seek to make SHHP 'work'. 5) Processes of experiencing change as a result of changes in material arrangements and routines. 6) If experiences are interpreted as 'working', this may reinforce current material arrangements, routines, and meanings of 'working'. Collectively, this may also contribute to meanings of 'working' circulating at the societal level.

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