EXTENSION OF A KNOWLEDGE AND SKILLS TAXONOMY TO INCLUDE A COMPLEX AND INTEGRATED SKILLS CATEGORY

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Abstract

Understanding the nature of the tasks to be performed by learners in online and conventional contexts is essential in designing effective training and education programmes. Task analysis also determines the knowledge, skills, and attitudes (KSA) to be developed during learning programmes and subsequently expected of individuals for competent performance of a task to the standard required. A taxonomy developed by the researchers has, to date, proved appropriate for analysis of most tasks however, a requirement for an additional category has emerged. Theoretical analysis of complex skills provides a basis for a working definition of a proposed integrated skills category.

Introduction

MacLean and Cahillane (2015) describe an updated reclassification of knowledge and skills (K&S) developed to provide a finer-grained approach to analysis of the K&S required in the performance of trained tasks. Accurate task analysis is an essential first step in the design of effective online and conventional training and education and describes what learners do and how they should perform a task or apply a skill. It is used to determine the operational components of job roles, identify the skills required and the way in which they are applied as well as to develop training objectives. Thorough analysis also determines how the performer of the task thinks before, during and after learning and what knowledge states characterise the tasks being trained (Jonassen, Tessmer, & Hannum, 1999). The reclassification, which is consistent with the psychological literature on human cognition, is organised into psychological components (categories) and provides a generic taxonomy of psychological domains against which job-related K&S can be aligned. As such it provides a basis for more detailed task analysis during training design. The taxonomy may be used in conjunction with the User Decision Aid (UDA) (Rose, Radtke, Shettel, & Hagman, 1985). The UDA is a methodology developed for predicting how rapidly individuals forget certain types of military task. Combined, the taxonomy and UDA provide knowledge of task retention and task type which may be used by training managers to design training and indicate how long K&S will be retained if they are not applied or practiced. The following section summarises the psychological knowledge and skill domains of the current taxonomy. It is followed by a proposal to extend the taxonomy with a new category, a discussion about the nature of complex skills, what type of skill it will represent and how this should be defined.

The Knowledge Domain

Knowledge precedes all other skills, whether technical or non-technical in nature, and can be examined outside of its relationship with any other type of skill as a distinct category to be addressed in task analysis and the design of training interventions. In the taxonomy, the knowledge domain refers to the explicit knowledge required to conduct a task such as facts, concepts and theories. For the purpose of this paper two particular knowledge states are recognised; declarative knowledge and procedural (skill-based) knowledge. *Declarative knowledge* is developed during the first stage of learning, e.g., what things are and why things work, and it includes facts, rules or information about a task. As such, it represents *explicit knowledge*. As it is further refined, declarative knowledge is converted into procedural knowledge to produce skill-based behaviour. *Procedural knowledge* refers to knowing the actions required for the execution of a task and how to carry them out; hence the behaviour or task execution becomes more automatic (Ritter, Baxter, Kim, & Srinivasmurthy, 2011). Knowledge or information about a task is available in both declarative and procedural forms. As task execution becomes increasingly automatic, performance is driven predominantly by procedural knowledge. Unlike declarative knowledge, procedural knowledge does not require the active maintenance of each step of task execution in working memory.

The Skills Domain

Broadly, skills can be thought of in terms of mental processing and intentional physical movement, i.e., cognitive skills and motor skills. Within the taxonomy these broad skills areas are refined and organised into four categories of skill encountered in the literature: procedural skills, discrete psychomotor skills, continuous psychomotor skills, and decision-making skills. Drawing on MacLean & Cahillane (2015), these are summarised as follows:

Procedural skills. Procedural skills underpin the application of many military activities. Tasks requiring the application of procedural skills consist of a number of coherent steps. In turn, these steps include the application of both cognitive and motor skills. Within tasks which are considered as predominantly procedural the motor element is minimal. Where the motor element is more prevalent, a task falls into the discrete psychomotor skill category.

Discrete psychomotor skills. Discrete (closed loop) skills involve the application of physical movements to tasks with definite beginnings and endings executed in sequences of steps. Stripping and assembling a weapon is a good example of a task requiring the application of discrete psychomotor skill. In this example, an individual is required to remember a sequence of component steps within a *Skill at Arms* drill, whilst performing the physical/motor component, of manipulating the respective parts and characteristics of the rifle. They are dependent on procedural knowledge and memory for the order in which steps are performed and are also referred to as procedural skills.

Continuous psychomotor skills. Continuous (open loop) skills are characterised by repeated actions or steps with no distinct beginning or endings, such as flying an aircraft, driving a vehicle, typing, or keeping a weapon sight on a moving target. These types of activity are also referred to as perceptual-motor skills.

Decision-making skills. Skills in the decision-making category require the application of cognitive processes such as judgement, problem-solving and analysis in order for an individual to arrive at a decision. Two tasks representative of these skills are troubleshooting faulty equipment (which involves the use of reasoning skills in order to identify the problem) and the interpretation of topographical maps to identify symbols with terrain features on the ground.

Application of the Taxonomy

When applying the taxonomy in the analysis of tasks and job-roles, it is important to identify the sub-tasks which form the main task. Doing so identifies the category of skill that best reflects the task. For training managers, identification of this category is important when developing effective strategies for prioritising and sequencing training. Examples of military skills and tasks where the taxonomy has been used successfully to identify the main psychological skill categories include: map reading and navigation; tactical information and communications systems; driving; vehicle maintainer skills; operational law, and weapon handling.

In its current form, the taxonomy is primarily used to identify which psychological skill component is prevalent during successful execution of the task. In the case of certain types of task and sub-task, detecting the precise category of skill that best reflects the task is likely to be more problematic. Take, for example, analysis of a pilot taxiing an aircraft. This reveals that multiple procedural, discrete, and continuous psychomotor skills are being performed in parallel (Schoelles & Gray, 2012). Where a task requires this type of skill complexity, no single category can be said to reflect what psychological skill is being deployed during its execution.

Extending the Taxonomy

It is apparent that the complexity of some tasks presents an obstacle in applying the taxonomy for conducting fine-grained analysis of tasks. Nevertheless, it is an obstacle that has to be broken down, understood and addressed in the acquisition and retention of K&S (Farr, 1987; Sabol & Wisher, 2001). This is especially so in organisational training and education contexts such as that of defence where the overall successful performance of the organisation is dependent on the effective training of individuals. In order to deliver training and education to large numbers of learners defence organisations, as with higher education institutions, often opt to use information and communication technologies (ICTs) to support learning. As a result, defence has an increased need for learning technologies including simulators, virtual learning environments, mobile learning platforms, and virtual-part task trainers. Task analysis and the design of training and education, should ensure that there is successful alignment of the task to be trained with training methods, media, and appropriate learning technology, which in turn should support successful individual execution of trained tasks in the operational environment thus contributing to overall organisational performance.

This alignment and the fact that some skills are complex was taken into account when the taxonomy was developed. However, during application it emerged that for some tasks, not just complexity but also the notion of concurrent or parallel activity being addressed together in a distinct psychological skill category required attention in order to be able to make more accurate decisions regarding the most appropriate strategies, methods, media, and learning technologies to be used. Extending the taxonomy to address the problems raised by parallel processing or concurrency and related concepts during analysis will improve its utility and broaden its application. Next we discuss the nature of complex skills, task complexity, parallel performance, and their implications for the taxonomy. Finally, we tentatively propose a working definition for a new skill category within the taxonomy.

Complex Skills

Skill complexity is a recurrent theme in the psychological literature with varying descriptions and explanations. The term complex skill is often used without further qualification although more descriptive terms are also encountered such as *complex motor skill* and *complex cognitive-motor skill*. An overview of the results from a search of the literature using these terms suggests that these types of skill are mostly encountered within sports psychology research. This is possibly due to inclusion of the *motor* component. Complex skills (minus the motor component) are also found in the literature of training and education where the term *complex-cognitive skill* is used to categorise tasks such as complex decision making, information problem solving (Villado et al., 2013), computer programming, fault diagnosis, military air weapons control (Merriënboer, 1997), etc. Because of the range of terms used to describe skills, some thought has to be given to their precise nature in order to identify the most appropriate category to use.

Dimensions of Complexity

It follows that where tasks are complex, they are likely to require the application of complex skills. Gaining an overall measure of complexity is not only important for making decisions about training but also because it is *highly predictive* of whether a task, once acquired, will be forgotten (Sabol & Wisher, 2001, p.64). These authors describe the components of complexity that need to be understood in order to predict forgetting as: (a) the number of steps in a task, (b) whether the steps are to be performed in a sequence or not, (c) the presence of built-in feedback indicating correct performance of the task. Moreover, complexity and the need to remember a task are increased when a task involves procedures set among others which have no fixed organisation. Due to the relationship between these components and skill acquisition and retention, they were taken into account when the taxonomy was developed.

Within the taxonomy, complex motor and complex cognitive-motor skills are accounted for under the continuous and discrete psychomotor skill categories. Where the degree of cognitive processing required in performance of a complex cognitive-motor task increases to the extent that the motor aspect of the skill is secondary to the cognitive aspect, the skill becomes situated within the procedural skill category of the taxonomy. If there is little or no procedural knowledge required, the highest forms of cognitive-motor skill, once automatized, are placed in the continuous-psychomotor category, e.g., piano playing (Fitts & Posner, 1967). Identifying whether a skill has a greater or lesser cognitive component can present a challenge during task analysis using the taxonomy. The following example of speech production highlights the problem of how we might perceive a task requiring a high degree of cognition and motor movement and as a result, struggle to categorise it accurately.

Speech production requires very fine motor skills supported by complex cognitive processing. It involves a process of conceptual preparation, grammatical encoding, morpho-phonological encoding, and phonetic encoding before speech can be articulated. Articulation in itself is a fine motor skill requiring manipulation of intricate articulatory apparatus of which the tongue is just one part. The various physical components of the articulatory apparatus have to be controlled; breathing which gives the air supply needed for acoustic energy; the muscles of the laryngeal system which control voicing and loudness; and the vocal tract, for control of the timbre of vowels and the tongue, velum, and lips which control the way in which sounds are formed (see Indefrey & Levelt, 2000). Given these aspects, task analysis for training of a military linguist might identify articulation of speech as the dominant skill during certain tasks, and, therefore, it will rightly remain in the continuous psychomotor skill category. However, it is most probable that tasks requiring speech will act as an enabler to skills aligned with a more dominant category.

Performance of routine radio communications between the pilot of an aircraft and air-traffic controller would, therefore, be classed as a procedural skill even though it also requires speech production and involves physical operation of radio equipment; while still maintaining flight control of the aircraft. Thus, even a complex task such as in-flight radio communication might still be classified accurately because even the flight-control aspect, a continuous psychomotor skill, has been automatized to the extent where it is still secondary to the task of communication. Even apparently complex tasks can be successfully aligned with the taxonomy however, given that some tasks still do not appear to align with a single category, questions remain about the nature of apparently complex tasks and how we can determine the point at which a new category is required.

By examining the way in which tasks and tasks elements are organised and the relationships between them we can gain a better sense of a task’s complexity. Elen & Clark (2006) acknowledge that as the number of elements in a task and the number and diversity of relationships between them increase along with change over time, tasks become more complex. Their discussion is presented in light of Dörner’s (1996) view that task complexity cannot be calculated objectively and must take into account the subjective experience of the task performer or learner and the relationship between their characteristics and that of the task. This perspective differs from that of the taxonomy which considers the task objectively and independent of the subjective experience of the performer. However, the basic starting point for analysing the components of a task outlined above reflects two earlier theories of task complexity developed by Wood (1986) and Campbell (1988). Both take into consideration individual characteristics but set aside individual experiences while performing the task.

Although task analysis as such quite often relies on subjective perceptions of tasks, without a formal definition task characteristics become confounded by task and non-task elements "particularly interactions between task attributes and individual attributes" (Wood, 1986, p.61). If we are to establish which category in the taxonomy best reflects the task and objectively assess what is going on, Wood's theory is helpful. It identifies three constructs foundational to the definition of task complexity: products, acts, and information cues. *Products* are the specified and objectively measurable outputs resulting from the execution of a task. Acts are inputs in the form of behaviours or *components* required in creating a defined product. The direction of the act is implicit in the verb used in reference to it which indicates the level of the mental and physical activities within the act; verbs separate one act from another, e.g., walking, reading, identifying (p.65)Information cues are also inputs that must be consciously attended to and processed in judgment and inferential acts. Acts and information cues set the upper limits of knowledge and skill required for successful performance of a task. The relationships between the inputs determine the behavioural and processing demands placed on the individual. Within Wood's theory of task complexity three types of task complexity are defined.

Component complexity increases as the number of acts to be performed in a task and information cues requiring attention also increase thus placing greater demand on the K&S of the individual. Component complexity has a direct bearing on cognitive processing and memory requirements during performance. However, it may be moderated by component redundancy whereby the K&S required for one act generalise to another thereby reducing the level of cognitive processing and memory required.

Coordinative complexity refers to the nature of the relationships between task inputs and products. This type of complexity is of particular interest to the present study because as a concept it seeks to understand aspects of tasks relating to sequencing, timing, frequency, dependency, and location and is of particular importance in non-linear tasks which may require simultaneous performance of several acts and events. It is worth noting that this supports Sabol and Wisher's (2001) view of complexity as a task factor that severely impacts retention: "A complex task is the opposite of one with an inherent organisation that produces a 'simplicity' or unit where each task step follows logically from the one before" (p.64).

Dynamic complexity refers to the way in which change in the acts, information, or relationships between input and product vary over time. As a result, the knowledge or skills required for a task also change. For example, in multi-stage decision making, variations in the relationship between the values within information cues as inputs and the outputs of judgments and decisions lead to a corresponding adjustment in the magnitude of dynamic complexity. If there is a single change in one of the dimensions, its effects may diminish over time but when it is continuous, dynamic complexity of the task will increase. Although the dimensions are not completely independent of each other, any shift in the complexity in one does not necessarily affect the others. However, various combinations across the dimensions will have differing effects on overall task complexity. Wood (1986) implies that the predictability of the change is a significant factor in reducing, over time, the initially high level of dynamic complexity.

Using Wood’s theory, task complexity can, to a certain extent, be analysed and understood. The increasing complexity of tasks, especially where the emphasis is on the coordinative relationships and requirement to be able to simultaneously perform several acts together, will require the ability to deploy skills from two or more of the taxonomy in a correspondingly coordinated and simultaneous way. As an example of coordinative complexity, Wood analyses the task of an air traffic controller landing a plane and the required acts and information cues. A point may be reached where complexity has increased to an extent where the individual’s capacity to perform effectively becomes *overloaded.*

There is no single type of complex task but the three types of task complexity in Woods’ theory provide an objective analytical approach to the overall complexity of a task and the K&S required to perform it. Echoes of Wood’s (1986) dimensions of complexity occur throughout the literature and theories of cognition related to understanding the nature of complex tasks for example, the overloading of capacity is very clearly explored in research using Sweller’s (1994) cognitive load theory. Understanding the nature of skill in the proposed category will likely entail a combining several theories and concepts. Some of these are briefly discussed below.

Simultaneously attending to multiple acts in a task with high dynamic complexity will require a type of ‘multi-tasking’ ability. Dzubak (2008) raises the idea that multi-tasking requires either task-switching or parallel processing of information. Whichever of these is considered, a higher degree of skill proficiency has to be acquired to reduce coordinative complexity through automatization of some aspects of the task. Several theories of skill acquisition have been put forward to explain the cognitive processes underpinning the acquisition of the type of internalisation and automaticity often associated with conceptions of expertise (e.g., Fitts & Posner, 1967). Although this model provides the foundation for all other models of skill acquisition, three stages remain common and consistent as an individual progresses from novice to skilled practitioner: the learning, associative, and internalisation stages. Progression through these stages of learning and development is characterised by an increase in the proceduralisation, durability and generalizability of K&S (Skinner, 2013).

How the stages of learning affect an individual's ability to cope with processing streams are also found in Campbell's (1988) theory where task complexity is directly related to the task attributes that increase information processing load. Differences in processing load at different stages of learning are illustrated by the example of flying an aircraft; it is easier for veteran flyers who have internalised the skills required and more difficult for novices who have to consciously recall and apply facts about a task to steer performance as they familiarise themselves with the basic rules and procedures underlying its execution and therefore find their processing capacity pushed to its limits. Campbell treats complexity as primarily a psychological experience which involves interaction between task and person characteristics and complex tasks are characterised by lack of structure, ambiguity, uncertainty, and difficulty. Complex tasks are by their nature difficult and the terms are sometimes used interchangeably. However, a task may be difficult because it requires more effort either physical or mental. The theory appears to suggest the presence of multiple *streams* of concurrent information processing and again appears to suggest multitasking.

For Loukopoulos, Dismukes, & Barshi (2009), multitasking is a loose term. Even when people appear to be performing two or more tasks at once, in all likelihood what is happening is

concurrent task management (p.11). Simultaneous task performance can only pertain to the types of situation described above where highly practiced tasks have become automated and do not require significant attentional resources. Tasks that have not been automated and are still in the early stages of skill acquisition (due to infrequent practice) require individual processing focused on one task at a time. What they propose is that pilots who appear to be multitasking or engaged in simultaneous execution of more than one task, are actually managing tasks concurrently. Thus, all but highly automated tasks are managed concurrently but executed sequentially - not simultaneously. Simultaneous execution is only possible with tasks that have been practiced to the point that they are automaticised and require minimal attentional resources.

Real-world tasks that pilots have to perform vary considerably from the ideal tasks described in flight operations manuals (Loukopoulos et al., 2009). The example of a cockpit crew at work is given to illustrate this situation and in which Wood's (1986) dimensions of complexity can be seen as the crew interact with other people both on the ground and in the air during the stages of flight. These people are continuously providing critical information to the crew and imposing demands that affect the timing and structure of the crew's other tasks. Furthermore, dynamic complexity increases significantly as a result of weather and other conditions. Closer analysis of pilot tasks in the example scenario would reveal high levels of component, coordinative and dynamic flexibility, and unpredictability. When several cognitive functions have to be managed concurrently during performance of a task, it becomes impossible to distinguish which category of the taxonomy is most appropriate to use. Therefore, when a combination of psychomotor and cognitive components such as declarative knowledge, a large number of steps in a procedural task, and decision-making are being attended to simultaneously, the task may be described as integrated (Skinner, 2013). As such, it requires coordination based on attentional processes and simultaneous processing of interacting knowledge elements (Kluge, 2014). Tasks with more skill components and a greater requirement for coordination are more likely to result in increased loading of intrinsic memory in multimedia learning tasks (Kirschner, Kester, & Corbalan, 2011). This is consistent with Wood's (1986) theory and the concept of coordinative complexity. It also illustrates the importance of taking into consideration Cognitive Load Theory (CLT) which differentiates between three distinct types of cognitive load: (a) intrinsic load essential to the topic or task being learned, (b) extraneous load imposed on the learner unnecessarily, and(c) germane load which results from cognitive processing required for learning (see, for example, Sweller, 1994; 2011).

Decomposition of tasks for analysis of the underlying skills required to perform them successfully is necessary if we are to understand how best to train individuals to proficiency in a wide range of contexts both online and conventional. However, if we are able to design effective online training and education such that it uses the results of fine-grained task analysis for optimised learning experiences, it becomes possible to consider the provision of ICT mediated training on a scale beyond the scope of conventional contexts. Consideration of the use of ICT in training solutions has become commonplace in training and education and as a result, online learning opportunities are encountered in a diversity of situations. However, as with conventional training and education there is always room for improvement in task analysis for the design of more effective learning, The taxonomy discussed throughout this paper has already proved useful in most contexts, however limitations have been encountered where concurrent application of several skills is required during performance of a complex task.

Proposed Definition for an Integrated Skill Category

Fine-grained analysis of most tasks under consideration for the design of training and educational interventions in organisational contexts will reveal the category of psychological skill that best reflects the task. It will also inform decisions about what, in any context, may be the most appropriate combination of methods, media, and learning technologies for training that task. However, from the preceding discussion it is clear that understanding and analysing certain types of task presents a greater than expected challenge since without a clear category, the consideration of how acquisition and retention of skills should be addressed is constrained. Further work is needed to explore and develop a new category. As a starting point, it would seem sensible to have a working definition for what that category might be, therefore, we tentatively propose the following on the understanding that, over time, it will be refined:

'Integrated skills are those where no single dominant category emerges during performance of a task with high levels of complexity and element interactivity whereby an individual has to coordinate the concurrent management of two or more skills for successful performance.'

Conclusion

This paper has presented a theoretical basis for extending an existing knowledge and skills taxonomy for task analysis, a critical step in the design of training. In its current form the taxonomy has been used for online and conventional training and education contexts. The taxonomy currently consists of five categories of psychological knowledge and skill domains. Ongoing research in aligning the taxonomy of psychological domains indicated a possible need to include a further category for considering complex integrated skills, which involve multiple components within an integrated task. The nature of complex skills has been discussed and a range of related theories and concepts briefly described. The discussion concluded with a proposed working definition for a new skills category. This is a tentative first step towards developing deeper insight into the nature of integrated skills.

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