

# Towards an Understanding of Shared Understanding in Military Coalition Contexts

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**Abstract**—Shared understanding is commonly seen as essential to the success of coalition operations, and current research efforts are attempting to develop techniques and technologies to improve shared understanding in military coalition contexts. In spite of this, our understanding of what the term ‘shared understanding’ actually means is surprisingly poor. In part, this problem is attributable to the difficulty in comprehending the true nature of understanding itself, although confusions also arise about the precise nature of the differences between shared understanding and ostensibly similar constructs, such as shared mental models and shared situation awareness. In this paper, we attempt to improve our understanding of shared understanding by exploring the nature of understanding, situation awareness and mental models. Following Wittgenstein, we suggest that understanding is best conceived of as something akin to an ability, and shared understanding is, we suggest, best conceived of as the sharing of individual forms of understanding by multiple agents. We further suggest that mental models may provide a mechanistic realization for some of the performances that manifest understanding, and that situation awareness should best be seen as a particular kind of understanding, namely a dynamic form of situational understanding. In addition to discussing the nature of understanding and shared understanding, we also discuss their potential relevance to military coalition operations. We propose that shared understanding is important to coalition operations because it contributes to improvements in coalition performance, the optimal use of limited communication assets, and an improved sense of group cohesion, group solidarity and mutual trust.

## I. INTRODUCTION

Shared understanding is a construct of apparent importance in military coalition operations. This is evidenced by anecdotal reports suggesting that shared understanding enables coalition forces to coordinate their efforts in respect of mission goals. Furthermore, major coalition-oriented research programmes, such as the International Technology Alliance<sup>1</sup> (ITA), have identified shared understanding as a hard problem for future coalition operations, and considerable research effort is now being invested into developing techniques and technologies

to support improvements in shared understanding. In spite of all this, the notion of shared understanding is something that is surprisingly hard to understand. The notion is clearly related to individual forms of understanding, but there is no real consensus about what the true nature of individual forms of understanding might be. Clearly, if we are to undertake research exploring the notion of shared understanding then it is important that we attempt to arrive at a clear definition of what the term ‘shared understanding’ actually means. Furthermore, we need to be clear about the precise inter-relationships between shared understanding and ostensibly similar notions such as shared situation awareness (SSA) and shared mental models (SMMs). In the absence of this kind of clarification, there is a danger that research efforts may be duplicated, or the relevance of particular research outcomes may be overlooked. In order to address these concerns, the current paper attempts to further our understanding of the notions of both understanding and shared understanding. The paper has four main aims: 1) to examine the notion of understanding and review ways in which the term ‘understanding’ is used (see Section II); 2) to examine the notion of shared understanding and review the forms that shared understanding may take (see Section III); 3) to compare notions of understanding and shared understanding with the notions of mental models and situation awareness (SA) (see Section IV); and 4) to assess the reasons why shared understanding may be important in military coalition contexts (see Section V).

## II. UNDERSTANDING UNDERSTANDING

In order to explore the notion of shared understanding it is first important that we understand what is meant by the term ‘understanding’. Unfortunately, as is evidenced by previous philosophical discussions on the topic, the task of understanding understanding is not one to be undertaken lightly [15]. Indeed, in the first chapter of his book, entitled *Understanding Understanding*, Paul Ziff [25] arrives at the rather dismal conclusion “that to understand understanding

<sup>1</sup><http://www.usukita.org/>

is a task to be attempted and not to be achieved today, or even tomorrow" (pg. 20). How, then, might we best make steps towards understanding understanding? In this section we pursue three approaches. Our first approach is to review existing attempts to understand understanding. In this case, perhaps the most notable contribution to the philosophical debate surrounding the notion of 'understanding' derives from the work of Ludwig Wittgenstein, particularly his work in the *Philosophical Investigations*<sup>2</sup> [24]. Another approach that we pursue in this section is to look at the various contexts in which the notion of understanding is commonly used. Understanding thus emerges in discussions of how we make sense of various things, such as sensory stimuli, intentional actions, words and sentences, and situations. By examining the use of the term 'understanding' in these various contexts, we may perhaps arrive at a better understanding of what understanding actually means. Finally, we attempt to consider what it is that makes understanding so difficult to understand than others. If we consider what it is that makes certain things harder to understand than others, then perhaps we will arrive at a better understanding of the thing that is perhaps the most difficult to understand: understanding itself.

#### A. Wittgenstein and Understanding

Perhaps the best starting point in our effort to understand understanding is to consider previous attempts to make sense of the notion. In this respect, the work of Ludwig Wittgenstein, particularly his work in the *Philosophical Investigations*, is a major focus of attention. Understanding is one of the central themes of the *Philosophical Investigations*, and throughout Sections 143–242 Wittgenstein attempts to analyse the relationships between understanding and such categories as states, processes, events and abilities. The culmination of this analysis is the claim that understanding is something akin to an ability. To understand, claims Wittgenstein, is to be able to do certain things. Thus, to understand a sentence is to be able to do things that involve the sentence, e.g. to apply it correctly, to paraphrase it and to respond to it in appropriate ways. Similarly, to understand a word is, *inter alia*, to be able to use it correctly.

By casting understanding as a kind of ability, Wittgenstein hopes to avoid a number of confusions and pitfalls regarding a philosophical grasp of understanding. In particular, he is keen to resolve a number of categorization errors that may result from a reflection on the nature of understanding. One such category error is the notion that understanding is a kind of experience—the kind of experience we have when we feel we understand something, or when we suddenly gain insight into some previously ill-understood phenomenon. Although tempting, this view of understanding is misconceived. It is misconceived for a number of reasons, not least because we may feel we understand something even when we do

<sup>2</sup>Clearly, there have been many attempts to understand understanding other than those of Wittgenstein. Føllesdal [6] for example sees understanding as a kind of knowledge. For reasons of space we refrain from a more complete survey of the relevant philosophical, psychological and linguistic literatures.

not, in fact, understand it. In addition, a description of the various experiences that accompany understanding does not seem to capture the true essence of understanding. A person may have many experiences when they understand something, and none of these seems sufficient (or indeed necessary) for our ascription of understanding to a person—we do not say that someone understands something in virtue of the kind of experiences that they have.

In addition to discounting the idea that understanding is an experience, Wittgenstein also rejects the idea that understanding is a mental state or a mental process (see [1] for further discussion). As we will see in Section IV-B, this conclusion perhaps enables us to resolve a particular point of contention in discussions of SA: the apparent duality of SA as both a state and a process [see 17].

#### B. Varieties of Understanding

One of the things that may complicate an understanding of understanding is that the term 'understanding' is used in many different contexts. In addition, the objects of understanding—the things that are actually understood—are highly disparate and diverse. Although there have been some attempts to identify the common characteristics of things that are the legitimate targets of understanding [25], it is by no means clear that the various things we can understand do, in fact, constitute a unified category. In addition, as mentioned in Smart et al. [21], it is unclear whether the notion of understanding that is used in the context of language understanding is the same as that used in the context of understanding intentional actions or in understanding a particular situation. By looking at the various ways in which the notion of understanding is used in different contexts, we may be able to ascertain whether understanding can be treated as a unitary concept and, moreover, determine what its essential properties are.

1) *Sensory Sense-Making*: One context in which the notion of understanding has been used is in philosophical and psychological discussions of perception. Perception, it has been argued, depends on more than just an ability to detect stimuli; it also depends on an ability to make sense of them—to understand them. Support for such a view derives from the various cases of cataract surgery that have been undertaken with congenitally blind individuals. Although such surgical interventions were intended to restore the sight of patients, their success was limited to the restoration of something more limited: an ability to merely *sense* visual stimuli but not *perceive* them [23]. Sensation is not the same as seeing, it is argued, because seeing requires an ability to make sense of visual stimuli, to appreciate their significance and implications for future action. "To see", writes Noë [10], "one must have visual impressions that one *understands*" (pg. 6) [original emphasis].

If perception is predicated on some form of understanding, what might that understanding consist of? According to one increasingly popular theory, the content and character of our perceptual experience derives from our (implicit) knowledge of what are called 'sensorimotor dependencies' (i.e. our knowl-

edge of the relations between movement or change and the resulting patterns of sensory stimulation) [10, 11]. To perceive, on this view, is to be in possession of a body of (largely non-conscious) knowledge concerning the way in which patterns of sensory stimuli will change as a function of behaviour. In order to have the kind of phenomenal experiences we do (the sights, sounds, feelings, or whatever), we need to learn about the predictive relationships concerning the way in which our own behaviour affects sensory inputs. To understand then, on this view, is to be in command of a kind of predictive ability, an ability to appreciate the sensory consequences of motor actions and to coordinate behavioural output accordingly. Such a view has much to commend it in terms of what we know about the functional operation of certain brain circuits<sup>3</sup>. It also aligns itself pretty closely with Wittgenstein's notion of understanding as akin to an ability—the ability in this case is to predict or anticipate the sensory consequences of movement or change.

2) *Understanding Intentional Actions*: Another context in which the notion of understanding is used is in the understanding of intentional action. In order to make sense of one another's actions, we seem to rely on a folk-theoretic framework that emphasizes the causal relevance of certain mental states and processes. Thus, in order to make sense of a person's actions, we say that they must have certain beliefs and desires and that those beliefs and desires are causally-relevant to the actions that we observe. Understanding, on this view, seems to take the form of an ability to account for, or explain, a person's actions with respect to a particular theoretical framework. We might also be inclined to say that a person understands someone's actions if they are additionally able to predict what someone will do in light of the possession of certain mental states.

One way in which we may be able to understand the actions of other agents is by a process of mental simulation; i.e. mentally simulating the observed actions of another in order to infer what we ourselves would need to think and feel in order to express the same action in the same context. This simulation-based view has much in common with the views of the German sociologist, Max Weber. Weber advocated an approach to understanding human action that is grounded in the notion of *verstehen* (German for 'understanding'). This approach emphasizes the importance of 'putting oneself in the mind of others', of trying to understand human action by knowing what in oneself would need to be the case in order for the action to be expressed. Recently, of course, a rich theoretical and empirical literature has emerged regarding the role of so-called 'mirror neurons' in our ability to understand (to make sense of) the actions of others [7, 14]. Such mechanisms may be relevant to understanding in a variety of contexts, most notably our understanding of linguistic utterances. One, admittedly speculative, proposal that we want to raise here

<sup>3</sup>Many neural circuits in the brain seem to be involved in the computation (and minimization) of prediction error signals; i.e. signals that represent the error between a predicted pattern of activity and the actual activity generated as a result of internal or external events [18, 19].

is that mental simulation processes could be used to support an understanding of the *pragmatics* of spoken language. The general idea is that in order to understand why a particular speech act was performed, one might mentally simulate what was said in a given context in order to determine the kind of mental states (e.g. intentions) that would lead to the expression of that act. In support of this claim, there is some evidence that our perception of speech sounds involves the activation of those motor programs that would be used to produce the same sounds [13].

3) *Language Understanding*: The topic of language understanding is a vast and complex topic, and it is impossible to do justice to the various theoretical and empirical contributions in a paper of this length. Wittgenstein's views have been very influential in guiding the philosophical debates over language understanding, and, as mentioned in Section II-A, Wittgenstein sees language understanding, and perhaps all forms of understanding, as akin to the possession of an ability, power or capacity. For Wittgenstein, understanding a language is a matter of being able to do things (many different things), and these performances underwrite the ascription of understanding—they are criteria against which we judge whether someone understands (or does not understand) a particular linguistic expression.

Going beyond the philosophical debates, most of the empirical work that has been undertaken seems concerned with an elucidation of the cognitive processes that are involved in both language comprehension and language production. Influential work in this area includes Kintsch's [8, 9] construction-integration model for discourse comprehension. The model involves the construction of an initial set of propositional representations (representing the meaning of one or more sentences), followed by a process of propositional elaboration and then refinement and integration. The end result of these elaboration and integration processes is a situation representation, or a mental model, describing the situation referred to by the original sentences. An alternative view of language comprehension is provided by perceptual-simulation theory [26, 27]. This theory claims that language understanding involves the perceptual simulation of the situation(s) referred to by linguistic utterances or written narratives.

4) *Situational Understanding*: The notion of situational understanding is something that seems very similar to the notion of SA. Situational understanding involves an ability to explain how the current situation, or elements thereof, came to be as they are, and it often involves an additional ability to predict how the current situation may develop or evolve in the future. Situational understanding therefore seems to be based on the possession of certain predictive and explanatory abilities, abilities that seem to be based on knowledge about the kind of causal relationships that exist between various situation elements. Crucially, situation understanding seems to be based on an ability to infer the existence of unseen, or unobserved, elements of the current situation. Thus, explanation and prediction rely on retrodictive and predictive inferences about states-of-affairs that are not currently accessible to an

observer. This ability to ‘see more than meets the eye’ may be a common characteristic of many forms of understanding. In the case of sensory sense-making, for example, we spoke of an ability to predict the sensory consequences of movement; in the case of understanding intentional actions we spoke of an ability to infer the existence of causally-relevant mental states; and in the case of language comprehension we spoke of a collection of abilities that could be construed as dependent on a capacity to ‘see beyond the symbol’; i.e. to infer the semantic referents of particular linguistic expressions.

### *C. Why is Understanding Understanding Difficult?*

As mentioned in the introduction to this section, understanding is commonly seen as something that is difficult to understand. Why might this be so, and can we learn anything about the nature of understanding by considering why understanding is so difficult to understand? According to Ziff [25], understanding is essentially an analytical process whose difficulty is related to the structural complexity of the object to be understood. Rosenberg [15] extends this analysis by including two additional factors that may make something difficult to understand. One is the need to put an object of understanding in its proper context, of establishing a network of relationships between the thing to be understood and other elements of the surrounding context. Rosenberg [15] argues that this is not a process of analysis, as Ziff [25] seems to suggest; it is more a case of synthesis, of “bringing things into relation, of building up a network of connections, interdependencies and affinities” [15, pg. 33]. An ambiguous sentence or word is thus disambiguated by establishing relationships between the sentence or the word and a number of surrounding contextual elements.

The second additional factor that Rosenberg [15] claims is a contributing factor to the difficulty in understanding something, is the vagueness or indefiniteness of the thing to be understood. What makes something difficult to understand, on this view, is the difficulty we have in identifying legitimate instances of the thing we seek to understand.

We therefore confront three sorts of reasons as to why something is difficult to understand. Something may be difficult to understand because 1) it is structurally complex, 2) because it is incoherent and ambiguous (i.e. it fails to cohere with the elements of a larger nexus of contextual elements), or 3) because it is vague and indistinct. In general, things that are difficult to understand all seem to involve a knowledge or awareness of the relationships between various things. Thus, in the case of things that are structurally complex we need to know or be aware of the relationships between constituent parts of the object of understanding; in the case of things that are incoherent or ambiguous we need to know or be aware of the relationships between the object of understanding and the wider relationships it has to external or surrounding objects; and in the case of things that are vague we need to know or be aware of the relationships (properties) that dictate the conditions of category membership.

So understanding may be difficult to understand for a variety of reasons, all of which seem to involve, to a greater or lesser extent, our ability to know, identify, learn, discover, or use the relationships or connections between things. In the case of understanding, it may be that the relationships in question concern those with concepts such as ‘meaning’, ‘knowledge’, ‘ability’, and ‘explanation’, each of which is, in turn, difficult to understand. Alternatively, the relationships may concern those associated with the identification of particular instances of understanding. The large variety of things that can be understood, as well as the large number of disparate performances that seem to manifest understanding, may lie at the root of this particular difficulty. Whatever the reasons for the difficulty in understanding understanding, the main point of this discussion is that it perhaps reveals something of the nature of understanding (i.e. what it means to understand). Our analysis suggests that understanding seems to involve (and is perhaps constituted by) a particular form of knowledge, namely knowledge about the inter-relationships between various things. In order to understand something it seems to be important that relational knowledge is suitably poised to influence, guide and constrain thought and action in various ways.

### *D. What is Understanding?*

We have now scouted some of the intellectual terrain associated with the notion of understanding. Does this peregrination enable us to better understand understanding in any way? And can we, in virtue of this understanding, propose an adequate definition for both understanding and shared understanding? In a previous paper, we defined understanding as “an ability to exploit bodies of causal knowledge (i.e. knowledge about the antecedents and consequents of particular phenomena) for the purpose of accomplishing cognitive and behavioural goals” [21]. Understanding was thus cast as particular form of ability, and the ability in question related to the exploitation of causal knowledge. In part, this definition was motivated by an attempt to account for the predictive and explanatory performances that seem central to many cases of understanding (see Section II-B). Seen in the light of the current discussion, however, the definition proposed in Smart et al. [21] does not seem quite right. While it does seem appropriate to regard understanding as a kind of ability, it does not seem entirely appropriate to *equate* the notion of understanding and ability (see discussion in [1] for more on this). In addition, the attempt to equate understanding with a particular kind of (albeit highly generic) ability now seems somewhat overstretched. It risks restricting the notion of understanding to a particular set of performances which may not cover the full range of cases in which ascriptions of understanding are made (the definition does not, for example, seem to apply to cases of language understanding). What might be a better approach is to say that a knowledge of causal (and perhaps other) relationships is a means by which the exercise of certain abilities is made possible. For example, the thoughts and actions that merit the ascription of situational understanding to an agent are

made possible by access to certain kinds of knowledge (e.g. knowledge about the causal contingencies between events). The understanding, in this case, is not the knowledge of causal contingencies *per se*; it is more the ability to make predictions and establish explanations about the situation in question. It is clear that one's background knowledge supports the exercise of such abilities, but it does not seem appropriate to equate understanding with such knowledge.

What about the third part of Smart et al's [21] definition—the part about the purpose of an ability being to accomplish cognitive and behavioural goals. The original motivation for referring to goals in this definition was based on the perceived importance of the flexible and adaptive use of knowledge in establishing genuine cases of understanding. Thus, in order to understand something, we claimed, one should be able to adaptively engage in thoughts and actions that realize some particular goal. Although we are aware of the considerable opposition to referring to goals in any definition of understanding, we think that goals may still be important in terms of understanding the nature of understanding. At first blush, it is somewhat difficult to see whether the notion of goals and understanding can really be disentangled; for inasmuch as understanding is akin to an ability, then the specific performances that manifest understanding may always be expressed in respect of some goal. For example, if we cast understanding as an ability to provide descriptions, explanations and predictions about (e.g.) a particular situation, then the goals of performances corresponding to the exercise of this ability are the ones to describe, explain and predict situation-relevant states-of-affairs. It is in striving to reach goals that the understanding of an agent is arguably demonstrated.

In summary, then, it seems that the notion of understanding is similar to the notion of an ability. To understand is to be able to do things. Typically, understanding is evidenced by our descriptive, explanatory and predictive successes regarding the object of understanding, but there does not seem to be any firm basis for saying that understanding is a particular form of ability, e.g. an ability to predict or explain something. It may be that, in many cases, the performances that manifest understanding require a knowledge of particular relationships (e.g. causal linkages), and it may even be the case that our ability to infer those (unseen) relationships is one of the criteria for (some forms of) understanding; nevertheless, it seems unlikely that the generic notion of understanding can be equated with any particular set of abilities.

### III. SHARED UNDERSTANDING

#### A. *What is Shared Understanding?*

If understanding is akin to an ability, what might shared understanding be? The most obvious answer to this question is that shared understanding is an ability (or something similar to an ability) that is common to multiple agents. But now we face a dilemma. If understanding is akin to an ability, then it cannot be that the behaviours that manifest shared understanding are the same for each agent. This is because the exercise of an ability is not the same as the ability itself, and the behaviours

corresponding to the exercise of an ability may be many and varied. As such, how do we ascertain that two or more agents possess shared understanding of some target object despite the fact that the performances manifesting such understanding may be multifarious?

The best we can do in this situation, it seems, is to determine whether the performances of the agents in question warrant the ascription of the same, or similar, kind of understanding. In this respect, similar performances by multiple agents may be sufficient to merit conclusions about shared understanding, providing that the nature of the performance warrants the ascription of the same (or similar) kind of understanding to each agent. Thus, two individuals who possess shared understanding will, at least in some cases, establish the same set of (e.g.) explanations and expectations given identical information about (e.g.) a situation (all other things being equal). In the case of medical diagnosis, for example, we might conclude that two individuals have the same understanding if they are able to account for symptoms in the same way and are additionally able to anticipate the same set of pathophysiological outcomes as a result of disease progression. In a coalition military context, we might say that two commanders have the same (i.e. shared) understanding of a situation if they are able to anticipate the same effects of military actions and are also able to cite the same reasons as to why particular military actions should be undertaken (e.g. to ensure the efficient realization of particular mission objectives). Clearly, the shared understanding that individuals possess (as determined by their predictive and explanatory capabilities) will not be identical in most cases. In addition, the shared understanding between individuals will rarely, if ever, be complete (see Section III-B); individuals will often possess limited forms of shared understanding that are specific to some particular situation or task context.

Although similarity of performances may be sufficient for conclusions about shared understanding, it should not be deemed as necessary. This is because different performances can still imply shared understanding. In discussions about military coalition operations, for example, the notion of shared understanding is typically seen as an enabling factor for what is called 'unity of effort'. This is the notion that coalition force elements, perhaps from different command structures, are able to coordinate their efforts in order to realize common mission objectives. The specific actions that constitute unity of effort are unlikely, it should be clear, to be the same across all force elements. Rather, what seems to matter is that the actions are, in some sense, complementary or compatible with each other (when evaluated with respect to mission objectives). Presumably, what supports the expression of these complementary or compatible actions is a shared understanding about a particular set of things, including (perhaps) an understanding of how agent roles, responsibilities, capabilities, and goals relate to shared mission objectives and the vagaries of the current situation.

### *B. Shared Understanding: Identity, Similarity or Complementarity?*

In addition to attempting to provide a definition of understanding and shared understanding, Smart et al. [21] also discuss a number of forms of shared understanding based on the extent to which the understanding possessed by multiple agents is the same. As Cannon-Bowers and Salas [2] point out in the context of shared cognition, the notion of ‘sharedness’ can be viewed in multiple ways. One interpretation of ‘shared’ is that it denotes the common or joint possession of some resource (e.g. the sharing of a belief or item of equipment). An alternative view sees ‘sharing’ as implying the division of a resource between multiple recipients (e.g. sharing the workload or sharing a dessert). This latter notion of sharing is particularly relevant to team situations because teams typically feature a degree of specialization in which each team member undertakes a particular task, or element of some larger joint task. When it comes to matters of understanding in team situations, it seems that identity or similarity of understanding may not always be the thing that is desired. Instead, what may be desired is a distribution of the responsibility for understanding something. In this case, individual team members might be expected to have a distinct understanding of different parts of the shared object of understanding (e.g. a situation or system). Smart et al. [21] identify this form of understanding as ‘complementary understanding’ and contrast it with two other forms of understanding: ‘identical understanding’ (the understanding possessed by two or more agents with respect to some target object is identical) and ‘similar understanding’ (the understanding possessed by two or more agents with respect to some target object is similar or overlapping).

## IV. SITUATION AWARENESS AND MENTAL MODELS

The notions of understanding and shared understanding are typically encountered in discussions of both mental models and SA in the human factors literature. This section aims to provide a better understanding of the nature and inter-relationships between these ostensibly similar constructs.

### *A. Mental Models*

According to Rouse and Morris [16] mental models are the “mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states” (pg. 351). Mental models therefore support the expression of particular abilities, such as those related to the description, explanation or prediction of certain things. When it comes to individual forms of understanding, therefore, we may see mental models as providing the mechanistic realization of specific performances that warrant the ascription of understanding to an agent [see 21].

In team situations, the notion of SMMs [3, 4] is typically encountered. SMMs are mental models that are possessed by multiple individuals, and they are assumed to benefit team performance by enabling individuals to anticipate one another’s

information requirements. Inasmuch as individual mental models provide a mechanistic realization for the performances that manifest individual forms of understanding, it seems likely that SMMs could support the expression of thoughts and actions warranting the ascription of shared understanding to a collection of agents. It is important to be clear what is and what is not being claimed here. One of the claims made in our previous paper [see 21] was that SMMs “may provide one means by which shared forms of understanding may be realized”. This is, in fact, subtly misleading because it implies that mental models provide a direct realization of, at least some kinds of, understanding. Instead, what seems more appropriate to say is that mental models support the expression of behaviours (thoughts and actions) that manifest understanding in both its individual and shared forms.

Another potential confusion, sometimes encountered in the human factors literature, is to equate the notions of understanding and mental models. This equation is misconceived because understanding is akin to an ability and abilities cannot be reduced to the things (vehicles) that explain the exercise of the ability. As Baker and Hacker [1] comment: “Science explains powers by discovering underlying structures, but it is a mistake to think that it reduces powers to the structure of their vehicle” (pg. 337).

### *B. Situation Awareness*

In addition to mental models, it is important to consider how notions of understanding relate to the concepts of SA and SSA. According to Endsley [5], SA is “the perception of the elements in the environment within a volume of space and time, the comprehension of their meaning and the projection of their status in the near future” (pg. 36). Two elements of this definition seem immediately relevant to our notion of understanding: comprehension and projection. Comprehension implies that individuals who possess SA are capable of interpreting, combining and prioritizing information. Projection, on the other hand, implies that individuals are capable of formulating expectations about the occurrence of future events and system states. On the basis of Endsley’s [5] characterization it would seem that SA is something that entails understanding, or at least a particular form of understanding. In fact, we suggest that SA is indeed best conceived as a particular form of understanding—what we refer to as dynamic situational understanding [see 20]. The object of understanding in this case is, somewhat obviously, a situation, and the performances that manifest dynamic situational understanding are those typically encountered in many cases of situational understanding; i.e. an ability to describe elements of the situation, to provide explanations as to how the current situation emerged, and to predict what the future evolution of the current situation is likely to be. These descriptive, predictive and explanatory capabilities are, of course, those that seem to be supported in the case of mental models. So perhaps an appropriate theoretical integration of the notions of understanding, SA and mental models is the following: mental models support the expression of behaviours that warrant the ascription of SA

to an agent, and SA is a particular form of understanding, namely dynamic situational understanding [see 20].

By casting SA as a particular form of understanding, we are able to deal with a number of issues that have proved contentious in the SA community. One of these issues is the apparent state/process duality of SA—the tendency for SA to sometimes be regarded as a state and at other times as a process [see 17]. By casting SA as a particular form of understanding, we can see that SA is, in fact, neither a state nor a process. It is neither a state nor a process because understanding is neither a state nor a process (see Section II-A). If this is true, it suggests that the claims of those on both sides of the state/process debate are mistaken.

## V. THE IMPORTANCE OF SHARED UNDERSTANDING WITHIN COALITIONS

As mentioned in the introduction to this paper, shared understanding is something that is seen as important to military coalition operations. However, the precise contribution of shared understanding to such operations is unclear. Perhaps the main reason why shared understanding is important relates to the need for coalition elements to coordinate their efforts in respect of some common or joint goal. In this case, shared understanding might fulfil the same function for military coalitions as mental models do in the case of team performance: it enables coalition elements to predict and anticipate one another's behaviours and information requirements. In the context of the SMM literature, the ability to anticipate information requirements and proactively provide information in advance of its actual use has been shown to improve team effectiveness in a number of empirical studies [12, 22]. Similar performance benefits might apply in the case of shared understanding and coalition operations.

Another reason for the apparent importance of shared understanding in coalition operations could relate to the efficient use of limited communication resources. Inasmuch as shared understanding contributes to the realization of efficient modes of inter-agent communication and coordination, it may have particular value in the context of coalition operations. This is because coalition environments are often resource-constrained environments in which power overheads and network traffic must be kept to a minimum. If shared understanding improves the efficiency of inter-agent communication (perhaps reducing the need for communication altogether), it may contribute to the optimized use of limited network assets.

In addition to supporting improved performance and optimizing the use of available resources, shared understanding may also be important for factors such as group cohesion, group solidarity and trust. Intuitively, it seems that an ability to anticipate the information needs of teammates and behave in ways that accord with the expectations of others could be a key ingredient of what it means for someone to be regarded as a 'team player'. Inasmuch as this is the case, we may expect shared understanding to be an important contributor to a range of psychoaffective outcomes, as well as group performance variables, in military coalition settings.

## VI. CONCLUSION

The primary aim of this paper has been to improve our understanding of both individual and shared forms of understanding. Such an improvement is important given the perceived significance of shared understanding to coalition operations and the current focus of ongoing research efforts into coalition capabilities (shared understanding has, for example, been recognized as a major research challenge in the context of the ITA programme). Unfortunately, the notion of understanding is something that has proved notoriously difficult to understand, and it is the source of considerable confusion in both the philosophical and scientific literatures. In a previous paper, we sought to resolve some of the confusion by generating a definition of understanding [21]. However, such attempts at a definition now seem somewhat premature. Given our current characterization of understanding and shared understanding, it may be that the search for a definition of understanding, at least one in terms of the essential features of understanding, is a fruitless undertaking. This is because understanding does not necessarily denote a specific ability, or set of abilities; rather, it is something that gets ascribed based on the exercise of many different abilities, and these abilities will vary based on the kind of thing that is the object of understanding. Perhaps the best that can be done in this situation is to resort to a strategy of ostensive definition, one that fixes the extension of 'understanding' by reference to specific examples of understanding.

In spite of the definitional difficulties, we have seen that the expression of behaviours that manifest at least some kinds of understanding (e.g. situational understanding and the understanding of intentional actions) do seem to have some common features. These include an ability to make inferences about the unseen and perhaps forever unobservable. In essence, what we encounter in many cases of understanding is an ability to 'see more than meets the eye'. Often these inferences give a predictive and explanatory grasp on the thing that is to be understood, and they often enable us to express thoughts and actions that are suited to the realization of diverse goals. Although we do not agree with Føllesdal [6] that understanding is a particular form of knowledge, it is true that, in many cases, understanding is evidenced by the expression of a flexible performance capability, and this seems to rest on an ability to use and exploit bodies of knowledge for particular purposes. Perhaps if we were to attempt to capture the essence of understanding, it would be this ability to use our knowledge in highly flexible, adaptive and context-sensitive ways that would most occupy our attention. Understanding often seems to be ascribed when people are able to use their knowledge to solve particular problems—the performances that manifest understanding are often cases of, what we might refer to as, 'knowledge in use'.

The characterization of understanding as akin to an ability sheds light on what it means to have shared understanding. Shared understanding, we have suggested, implies similarity of understanding with respect to particular things, e.g. goals,

tasks, and situations. In the case of coalition operations, the abilities that are likely to emerge as important are those related to the formation of expectations and predictions regarding future actions, events and information requirements. We have suggested that this view of understanding dovetails nicely with the prevailing literature on SMM and SSA. As such, the characterization that we have provided here may provide the basis for further advances in our understanding of understanding and its relationships to ostensibly similar constructs such as mental models, SMMs, SA and SSA.

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#### REFERENCES

- [1] G. P. Baker and P. M. S. Hacker. *Understanding and Meaning: Essays Pt. 1 (Analytical Commentary on the Philosophical Investigations)*. Blackwell Publishers Ltd, Oxford, UK, 1980.
- [2] J. A. Cannon-Bowers and E. Salas. Reflections on shared cognition. *Journal of Organizational Behavior*, 22(2):195–202, 2001.
- [3] J. A. Cannon-Bowers, E. Salas, and S. Converse. Cognitive psychology and team training: Training shared mental models and complex systems. *Human Factors Society Bulletin*, 33(12): 1–4, 1990.
- [4] J. A. Cannon-Bowers, E. Salas, and S. Converse. Shared mental models in expert team decision making. In N. J. Castellan, editor, *Individual and Group Decision Making: Current Issues*, pages 221–246. Lawrence Erlbaum Associates, Hillsdale, New Jersey, USA, 1993.
- [5] M. R. Endsley. Toward a theory of situation awareness in dynamic systems. *Human Factors*, 37(1):32–64, 1995.
- [6] D. Føllesdal. Understanding and rationality. In H. Parret and J. Bouveresse, editors, *Meaning and Understanding*. Walter de Gruyter, Berlin, Germany, 1981.
- [7] V. Gallese and A. Goldman. Mirror neurons and the simulation theory of mind-reading. *Trends In Cognitive Sciences*, 2(12): 493–501, 1998.
- [8] W. Kintsch. The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, 95: 163–182, 1988.
- [9] W. Kintsch. *Comprehension: A Paradigm for Cognition*. Cambridge University Press, New York, USA, 1998.
- [10] A. Noë. *Action In Perception*. The MIT Press, Massachusetts, USA, 2004.
- [11] J. K. O'Regan and A. Noë. A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, 24 (24):939–973, 2001.
- [12] R. Oser, C. Prince, and B. B. Morgan. Differences in aircrew communication content as a function of flight requirement: Implications for operational aircrew training. In *34th Annual Meeting of the Human Factors Society*, Orlando, Florida, USA, 1990.
- [13] R. J. Porter, Jr. and J. F. Lubker. Rapid reproduction of vowel-vowel sequences: Evidence for a fast and direct acoustic-motoric linkage in speech. *Journal of Speech, Language and Hearing Research*, 23(3):593–601, 1980.
- [14] G. Rizzolatti and L. Craighero. The mirror-neuron system. *Annual Review of Neuroscience*, 27:169–192, 2004.
- [15] J. Rosenberg. On understanding the difficulty in understanding understanding. In H. Parret and J. Bouveresse, editors, *Meaning and Understanding*. Walter de Gruyter, Berlin, Germany, 1981.
- [16] W. B. Rouse and N. M. Morris. On looking into the black box: Prospects and limits in the search for mental models. *Psychological Bulletin*, 100:349–363, 1986.
- [17] R. Rousseau, S. Tremblay, and R. Breton. Defining and modeling situation awareness: A critical review. In S. Banbury and S. Tremblay, editors, *A Cognitive Approach to Situation Awareness: Theory and Application*. Ashgate Publishing Company, Aldershot, England, UK, 2004.
- [18] W. Schultz and A. Dickinson. Neuronal coding of prediction errors. *Annual Review of Neuroscience*, 23(1):473–500, 2000.
- [19] W. Schultz, P. Dayan, and P. R. Montague. A neural substrate of prediction and reward. *Science*, 275(5306):1593–1599, 1997.
- [20] P. R. Smart. Understanding and shared understanding in military coalitions. Technical Report ITA/P12/Understanding, School of Electronics and Computer Science, University of Southampton, UK, in preparation.
- [21] P. R. Smart, D. Mott, K. Sycara, D. Braines, M. Strub, and N. R. Shadbolt. Shared understanding within military coalitions: A definition and review of research challenges. In *Knowledge Systems for Coalition Operations (KSCO'09)*. Southampton, UK, 2009.
- [22] R. J. Stout, J. A. Cannon-Bowers, E. Salas, and D. M. Milanovich. Planning, shared mental models, and coordinated performance: An empirical link is established. *Human Factors*, 41(1):61–71, 1999.
- [23] A. Valvo. *Sight Restoration after Long-Term Blindness: The Problems and Behaviour Patterns of Visual Rehabilitation*. American Federation for the Blind, New York, USA, 1971.
- [24] L. Wittgenstein. *Philosophical Investigations*. Basil Blackwell, Oxford, UK, 1967.
- [25] P. Ziff. *Understanding Understanding*. Cornell University Press, Ithaca, New York, USA, 1972.
- [26] R. A. Zwaan and M. P. Kaschak. Language in the brain, body and world. In P. Robbins and M. Aydede, editors, *Cambridge Handbook of Situated Cognition*. Cambridge University Press, Cambridge, UK, 2009.
- [27] R. A. Zwaan and L. J. Taylor. Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General*, 135(1):1–11, 2006.