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An Online System for Consensus and Opinion Development in Human Networks

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Abstract
The Opinion Development System (ODS), an online system for consensus and opinion development was developed as part of a collaboration between Northumbria University and the National NHS-E Community of Action for Trauma Informed Care (TIC). The aim was to determine if an online tool can help a group of people in an organisation to reach consensus (agreement) on some statements relevant to their field. Gathering a range of opinions and building consensus on these topics would inform the direction and strategy for the organisation.

A discrete dynamic opinion development method is implemented in ODS using an Erdos-Renyi network as the underlying communication network to support opinion and consensus development towards achieving a common shared goal among users in a multi-agent system. Erdos-Renyi networks are classical random graphs of nodes with independent edges mimicking connections between nodes or individuals. Each ODS user is assigned to a network comprising a subset of the overall number of users and only sees the views of that subset.

Individuals working in key leaderships positions in health care TIC practice and recovery were recruited to trial the ODS. Five-day trials were conducted. In each

case the system successfully established a network of connections between the participants (nodes), who then used it to view the opinion of others in their network on a topical issue and to regularly express their own views. The intention being to evaluate whether the sharing of views over time in such a network supports opinion and consensus development. The system did work as designed with users able to view the opinions of others and enter their own. Results indicated that there were changes in opinions which moved away from consensus (trial one) and towards consensus (trial two). However, there were an insufficient number of interactions to adequately measure consensus development fully (possibly due to staff workload) and to inform direction and strategy. We concluded that further research to consider ways of engaging participants and achieving more and sustained interactions considering the user perspective was required, for example by using switching networks, with larger groups.

Key Words: consensus, human networks, multi-agent systems, trauma informed care.

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Introduction

The pattern of behaviour of human networks emerges from the micro-interactions of multiple agents. Consensus building in such networks presents a complex context where patterns of opinion emerge without an intended blueprint. The theory of complex systems suggests that imposing order in a complex context will fail, but setting the stage, stepping back, allowing patterns to emerge, and determining which ones are desirable will succeed (Snowden & Boone, 2007). Thus, consensus building models need to be concerned with setting the 'right' conditions for opinion development to occur.

The purpose of this paper is two-fold: - review models of opinion and consensus building in human networks; - introduce an online implementation of an opinion development system and its application with staff from a large mental health provider in the UK.

Consensus and Opinion Development in Human Networks

Reaching consensus in a group of agents has become a key research topic in the field of multi-agent systems, where each agent has a state value and an agreement between their states is to be reached via local interaction with neighbouring agents in continuous-time or discrete-time. Consensus problems have been extensively studied by many researchers in the areas of control theory, physics, management, robotics, and mathematics with a wide range of applications in sensor fusion, flocking and swarming, formation control, unmanned aerial vehicles, as well as biological and social networks (Jadbabaie et al., 2003; Olfati-Saber et al., 2007; Qin et al., 2017).

According to Olfati-Saber et al. (2007), consensus means to reach an agreement on a quantity of interest that depends on all agents. This definition is based on dynamic agents. Consensus entails all agents converging on or agreeing to a common shared goal by implementing necessary protocols that signifies a rule of interaction for each agent to exchange information with his or her neighbour. The underlying connectivity of a communication network takes an essential role in maintaining the consensus behaviour of the whole system. For example, in Jadbabaie et al. (2003), global connectivity is assumed to guarantee the consensus behaviour. The condition can be relaxed to requiring a spanning tree structure of the network (Ren & Beard, 2005) and random networks have also been considered (Tahbaz-Salehi & Jadbabaie, 2008). When the network under consideration has certain robustness

meaning that some redundancy of edges exists in the structure, some faulty agents or malicious agents can be withstood (Shang, 2018b).

The convergence speed of agents' states has been a key metric in gauging the effectiveness of the consensus in a multi-agent system. In Li et al. (2011), finite-time consensus, meaning that agents are able to reach a common value in only finite time, is achieved by incorporating signum functions into the control protocols. Distributed consensus protocols have been proposed in Shang (2017) to achieve finite-time group consensus when the whole network can be partitioned in some way to disjoint subnetworks. Fixed-time consensus problems have been solved for discrete-time (Liu et al., 2017) and continuous-time (Tian et al., 2019) multi-agent systems, where the consensus time is independent to the initial states or configuration of the network.

In the setting of social dynamics, communication between agents are captured by a social network and the state of an agent is often handily represented by their opinion (Proskurnikov & Tempo, 2018). The consensus problem becomes a decision-making process in social networks which characterize a number of interesting social phenomena such as collective decision making, adoption of a belief, the rise and fall of a political party, polarization, and the emergence of fads, etc.

According to whether the opinion value of an individual is continuous or discrete, opinion consensus models can be roughly grouped into two classes. For continuous models, the H-K (Pineda et al., 2013) and Deffuant (Antonopoulos & Shang, 2018) models are two of the most popular opinion spreading models, where H-K uses the synchronized update rule while Deffuant uses asynchronized update. Both assume that individuals are only willing to change their opinions if their opinions are closer to those of others than a confidence threshold reflecting the limited confidence effect. In the category of discrete opinion models, prominent examples include the Galam majority-rule model (Galam, 2005), voter model (Herreriás-Azcué & Galla, 2019), and the Sznajd model (Karan et al., 2017). Surveys of various opinion dynamics in social networks can be found in Castellano et al. (2009) and Proskurnikov & Tempo (2018).

Chen et al. (2019) suggests that individuals' opinions in the real world are biased. Moussaïd et al. (2013) argue that at the scale of a social group, repeated influences

among group members may lead to a complex pattern of opinion dynamics such as consensus formation, but also polarization and so on.

Shang (2020) shed more light on the difference between a private opinion and an expressed opinion. It was concluded that opinion distinction often arises when some individuals feel pressured in an interaction group to conform to the norm. A common reason for the difference between private and expressed opinion is the pressure an individual gets to conform in a group situation. This pressure from other individuals can make one agree to opinions or beliefs different from their private ones. An example of when an individual expressed public opinion differs from their private opinion is described in the field study by Waters & Hans (2009). They found that more than one third of jurors on criminal jury panels would have privately voted against the jury's panel final decision. This means that one third of the panel had a private opinion which was different from the final decision but had to conform to the opinions of others. A work by Kuran (2019) created the word preference falsification which describes a situation where an individual consciously or sub-consciously altered their true opinion to get their desired result. Thus, social influence brings about unpredictability in a system and may unfavourably impact decision making (Lorenz et al., 2011).

For the purpose of this research, it is thus considered important to develop an opinion building system that allows for anonymous participation while supporting maximum participation of all users. The difference between the initial opinion of users and their final opinions will be analysed. Consensus levels will be explored.

Opinion Development System (ODS)

A discrete opinion dynamic method is implemented in the Opinion Development System (ODS) using an Erdos-Renyi network as the underlying communication network to support opinion and consensus development among users of the tool. Erdos-Renyi networks (Erdös & Rényi, 1959) are classical random graphs of nodes with independent edges mimicking connections between nodes or individuals. There has been a wealth of literature in mathematics on this topic and many recent applications have been found in network science and complex phenomenon in nature and society (Newman, 2018). For example, these networks have been used to study scholarly citation networks (Shang, 2018a) and globalization of natural resources (Tu et al., 2019).

In the context of our proposed opinion development system, users (i.e. nodes in the network) are required to register with the system in advance of the creation of the communication network and the start of the opinion and consensus development process. Basic demographic information like gender and age range is collected to facilitate later data analysis along with a unique username and password.

The ODS then creates a communication network for the registered users. An N by N random matrix with each element representing the existence or non-existence of a link between two users (nodes) in the network. A value of 1 in the matrix means there is contact between them while 0 means no contact. We specify the probability of turning 1 independently and hence the connections between two nodes are random and independent with any other connections. In this way, we create random Erdos-Renyi networks where each user is connected to a sub-set of the total number of users rather than all.

Users are next asked to login and read a statement. They are then asked to rate their level of agreement with it using a slider scale from 1 to 10, to express the reason for the rating and then to indicate their level of knowledge on the subject. This data is stored. Note that at this stage the user does not see the ratings or opinions of others. On subsequent occasions upon viewing the statement users are presented with and asked to view the agreement ratings of those with whom they connected to with the network. They are then asked to re-rate their current level of agreement with the statement and the reason for it and this data is again stored. These opinions were then available for the others in their network to view. Users are asked to login regularly and re-rate their level of agreement. Participants are anonymous to prevent individuals feeling pressured to conform to a group norm. By tracking changes in the levels of agreement over time we can evaluate the development of opinion building and consensus.

A self-monitoring facility is included with the ODS called ‘My forum’. This allows users to view their own entries for agreement levels and the reasons for them as they develop over time to aid self-reflection.

Application of the Opinion Development System with staff from trauma informed care in a mental health provider in the UK.

Background/context

There is significant interest in integrating Trauma-Informed Practices into mental health and wellbeing in the UK. Both Scotland & Wales already devote national resources to trauma-informed public services. These services incorporate the understanding that people using them may have experienced trauma and that this trauma may have impacted on them in ways which would influence their interactions with that service, e.g., they may find it difficult to form trusting relationships and not feel safe in services. Trauma-informed services, instead, are delivered in ways that prompt safety and trust and do not re-traumatise. The most crucial shift involves shifting from the thinking 'what is wrong with you' to 'what happened to you' (Harris & Fallot, 2001; Thirkle et al., 2018).

Policy and practice development and the implementation of TIC requires an ongoing participative approach (Thirkle et al., 2018). The ODS (described above) provides a structure for maximum participation and opinion sharing for each member of a group or community regardless of their status.

Individuals working in key leaderships positions, in trauma informed practice and recovery were recruited to trial the ODS. In total 14 participants were recruited which included programme managers, senior clinicians across a range of services (including adult, child and adolescents, forensic and learning disability), researchers and experts by experience - individuals who have accessed mental health services and are now employed by the NHS to help improve services. All participants were recruited using an invitation email which outlined the methodology and joining instructions. Ethics approval for the study was granted from Northumbria University, Newcastle.

The statements identified and used for opinion development in the ODS trial were current issues within the trauma informed care programme. The issues were recognised within programme management discussions and conversations between the programme lead, manager and senior researcher. Gathering a range of opinions and building consensus on these topics would inform the direction and strategy on the implementation of trauma informed care across the service. There were two trials. The statements used were:

1. Trial 1: The implementation and embedding of Trauma Informed Care in your service is dependent on engagement of senior leaders who are not involved in direct care.

2. Trial 2: We have limited budget on the Trauma Informed Care Programme. It is important to spend a significant amount on research in order to create an evidence base.

The system was open for five days for each trial, with participants encouraged to enter an opinion daily, based on their experience, knowledge and other participants opinions, available from day 2 onwards. All opinions submitted into the system remained anonymous.

First Trial

Fourteen participants registered with the ODS for the first trial out of which twelve entered opinions over a period of five days. The users were invited to give an agreement score regarding the given statement and to enter a relevant opinion, and to repeat the process regularly.

The engagement of the participants with the trial measured by the number of opinions each entered is shown in Table 1. Only 3 participants entered 5 or more opinions. There were 9 participants who engaged two or more times, while 3 participants engaged only once. The most engagement was for 3 rounds (4 participants).

Table 1 Participants' engagement for the first trial.

Number of opinions	1	2	3	4	5	6	7
Number of participants	3	1	4	1	1	1	1

The evolution of the agreement scores at each round of the trial is shown in Figure 1. Six out of the nine participants who engaged more than once changed their agreement score at least once through the course of the experiment, indicating that they have indeed been influenced by others' opinions. The biggest change in agreement for one participant was by 5 (from an agreement score of 10 to 5) for participant 12.

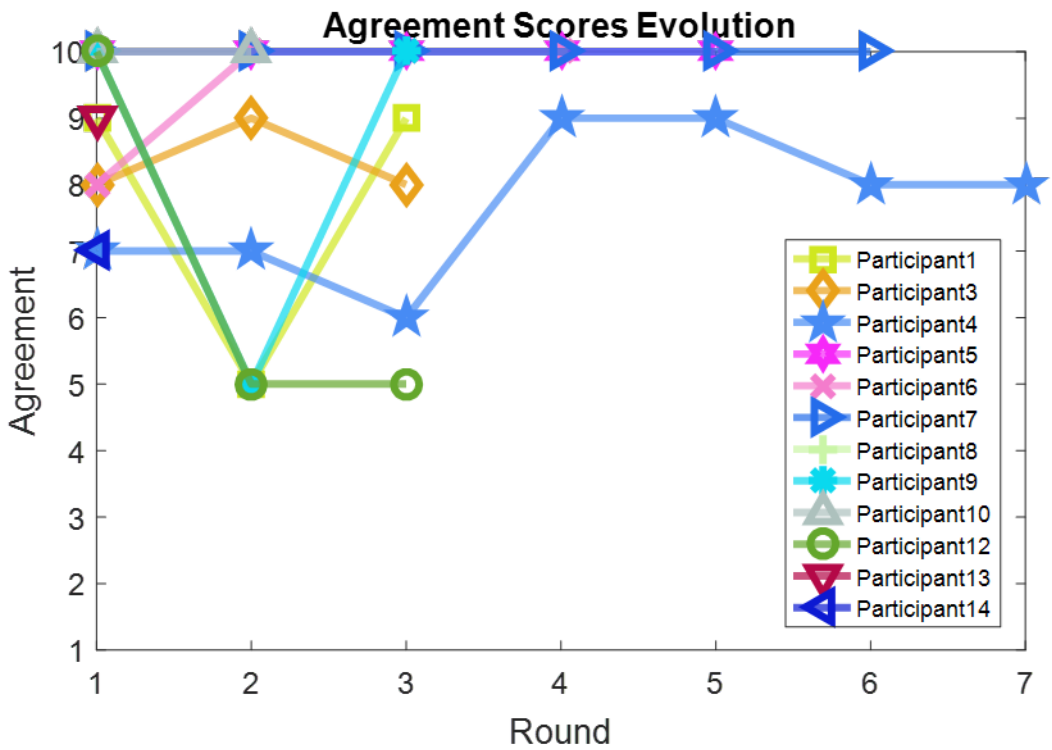

Figure 1 Opinion evolution for the first trial.

Second Trial

The second trial used a different statement. Thirteen participants registered for this trial out of which nine entered opinions at least once during the five days period. The level of engagement in this trial is shown in Table 2. Only 1 participant entered 5 opinions. There were 7 participants who engaged two or more times, while 2 participants engaged only once.

Table 2 Participants' engagement in the second trial.

Number of opinions	1	2	3	4	5
Number of participants	2	2	2	2	1

The evolution of the agreement scores at each round of this trial is shown in Figure 2. Five out of the seven participants who engaged more than once changed their agreement score at least once throughout the trial. The largest change in agreement scores is by 2, from 8 to 10 for participant 1, from 9 to 7 for participant 4, and from 4 to 6 for participant 11.

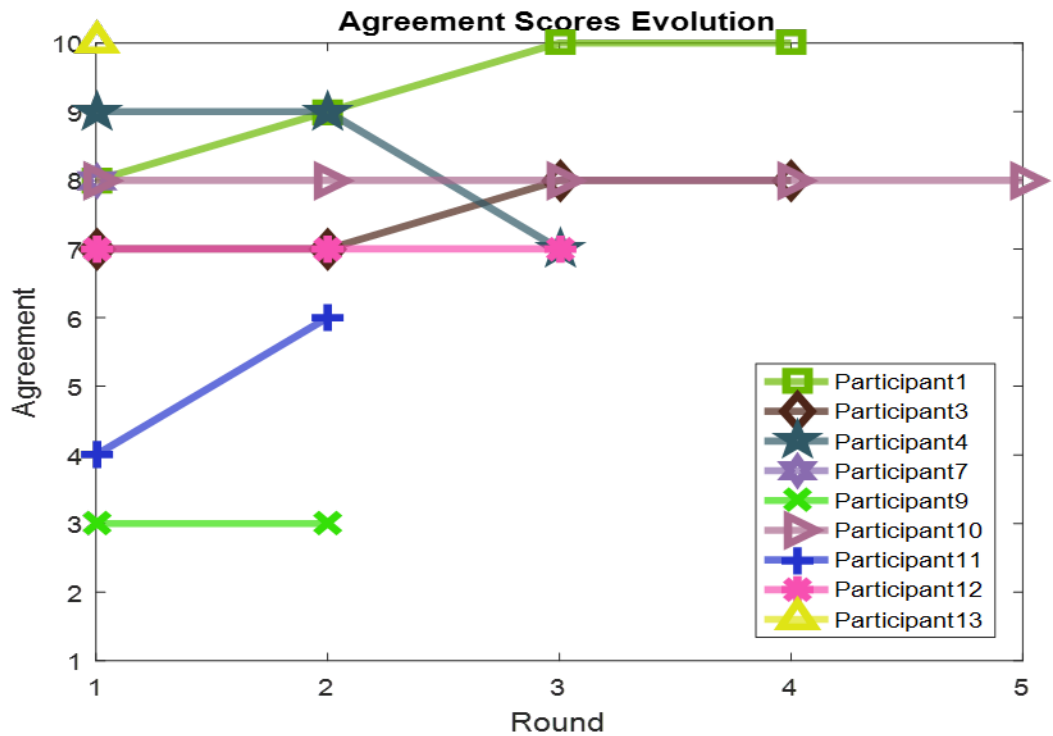

Figure 2 Opinion evolution for the second trial.

Summary Statistics

Since only a few participants engaged for the full five-day period by entering 5 opinions at least during both trials, we assume in the following that the last opinion given by a participant, no matter at which round, reflects an unchanged score afterwards. Although this assumption is reasonable, it may not be always valid. Ceasing to engage could be caused for instance by a lack of time, lack of interest in the topic, or other reasons unrelated to the participant having made a final decision on the statement.

We then compute simple statistical measures to compare the distribution of the agreement scores at the initial and final stages, such as mean, variance and range.

They can be seen in Table 3. For the first trial, the initial average level of agreement with the statement was 9 at the first round, it became 8.83 after the final round. The variance was initially 1.45, changing to 2.51, and the range (maximum – minimum) changed from 3 to 5. For the second trial, the initial average level of agreement with the statement changed from7.11 at the first round to 7.44 at the final stage. The variance was initially 5.11 and became 4.53, and the range remained unchanged at 7.

Table 3 Summary statistics for both trials.

	Trial 1		Trial 2	
	Initial	Final	Initial	Final
Mean	9	8.83	7.11	7.44
Variance	1.45	2.52	5.11	4.53
Range	3	5	7	7

Discussion

The Opinion Development System model was implemented successfully. Figures 1 and 2, show the data entries for each participant. Appendix A includes screen shots of the system, including opinions shared by participants. From the responses in Figure 1 we can see that those participants with more than two entries (participants 3, 4 and 12) did amend to an extent their initial opinions, as a result of viewing the opinions of their neighbours. The system works according to the structure described in the system implementation, with Erdos-Renyi network of neighbour nodes successfully established as a communication network to support opinion and consensus development. Users could review the opinions of the other participants they were connected to within the network on a given topic and were able to express their own opinions on it. These opinions were then available for the others in their network to view.

Data entries were analysed for convergence. From Table 3 we can draw the following observations. First, the mean value changes from an initial 9 to a final 8.83, which means that the opinion evolution shows a slightly decreasing trend in term of the score. We believe that this is most likely due to the workload of the

participants (NHS staff). In order to commit time to discussion, they need to see this process as having more value than other tasks needing their attention. Other issues may include the homogeneity of the participants or a lack of challenge in the topic. Second, the variance value increases from 1.45 to 2.52, which together with the change of range from 3 to 5 indicates that the opinions diverged during the evolution process. This can be explained as follows. Starting from the 4th round, only three participants (participants 4, 5, and 7) were still using the system involved and the number further drops to two starting from round 6. This implies that the underlying interaction network becomes literally too sparse to be adequately connected. Therefore, the consensus reaching assumptions (Ren & Beard, 2005) no longer hold. Third, the second trial suffers from similar issues. However, the drop of variance (in this case from 5.11 to 4.53) sheds a light on the consensus mechanism in action. The final opinion configuration shows a better focus compared to the initial opinion configuration.

This is research in progress. The system is at a prototype stage, and participants were asked to engage in exploring opinions. Following each opinion development and consensus building trial, the design team collected feedback from participants and reflected on the findings. From the perspective of the participants, it was important that they could see the anonymised opinion of other participants, as well as track the development of their opinions. The second trial revealed the need for more flexibility in adding actors to the network and this will be considered as a future development. The iterative approach of development allows for taking on board the requirements of the users.

The limitations of the studies are: a small number of participants; insufficient iterations of interactions over the communication network. As discussed, the limitations were possibly due to the participants being NHS staff who had little time to engage with the system.

Conclusion and recommendations for further research

A discrete opinion dynamic method was successfully implemented in the Opinion Development System (ODS) using an Erdos-Renyi network as the underlying communication network to support opinion and consensus development among users of the tool. The system functionality worked as designed with users able to view the opinions of others and enter theirs and participants found the system easy to use, however, there were insufficient iterations of interactions over the

communication network to reach consensus. Further research will be required to consider ways of engaging participants in more sustained interaction considering the user perspective. For example, the tool currently forms a communication network where individuals exchange opinion through a fixed neighbourhood to support communication and opinion sharing. However, to work this requires all nodes to be present (registered on the system) for the network connections between people to be formed. As users tended to register over a period of a week or more, that meant that they couldn't start to interact for some time in some cases. A consequence of this was a perceived drop in user enthusiasm. We suggest using random or switching networks (Suo, 2008; Pan, 2021) and allowing the network to grow over time by letting new users join so that the network is time variant (Oliva, 2012; Li, 2019] in future work. With this approach, upon registration the user will immediately be able to rate their agreement and express/share their views. As each new user joins the network, they will be added and the connections will be switched to allow each user to see a potentially different set of views and therefore the opportunity to absorb more opinions, interacting with different network neighbours as time goes on. These changes may also lead to quicker consensus formation.

Using switching networks may better reflect real social networks where we interact with different people to exchange opinions on a topic in homes/gyms/bars/workplaces/etc. and our collaborators evolve with time.

To further improve usability we also suggest enhancing the way opinions are viewed. Currently participant only see the two most recent posts from each person in their network. Instead, they we could allow them to see all of their views over time and their own in a scrollable area to support consideration of opinion development. This will provide a 'chat' like discussion board interface that is more familiar to users and so may encourage participation. In addition, we suggest providing graphs for the user depicting how their own agreement rating and the average rating of their network neighbours has changed over time, supplying users with further evidence to support opinion development.

The aid the next stage of development we will collect mini narratives followed by interviews with participants, to explore how they use the system and what cultural assumptions and beliefs influence their motivation, and participation. The Appreciative Inquiry Method (AIM) (Stowell, 2013) will be used during the interviews to elicit first individual and then second a combined map of user

requirements. The ODS prototype can be adapted to accommodate the requirements and context of the user.

We also suggest that the context and timing of participation with the ODS need to be considered as well as topics that provoke more debate, including ones that are broader in nature to interest a wider audience, so that clear trend may be shown along the evolution of opinion and the development of consensus. In particular we propose to:

1. Link an ODS opinion and consensus building exercise to a large national webinar to see if the process of engagement with ideas in the webinar motivates people to participate with the consensus tool. This will also hopefully engage sufficient users to provide more robust data for analytics around the processes of decision making.

2. Explore whether the tool is valuable as a single user instrument for gathering opinion on a subject rather than creating changes.

3. Link the evaluation of the subjective experience of using the tool to expand the system of interest and involve the users in exploring the transformation that they would consider valuable, to inform further systems development (Stowell and Welch, 2012).

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Appendix A

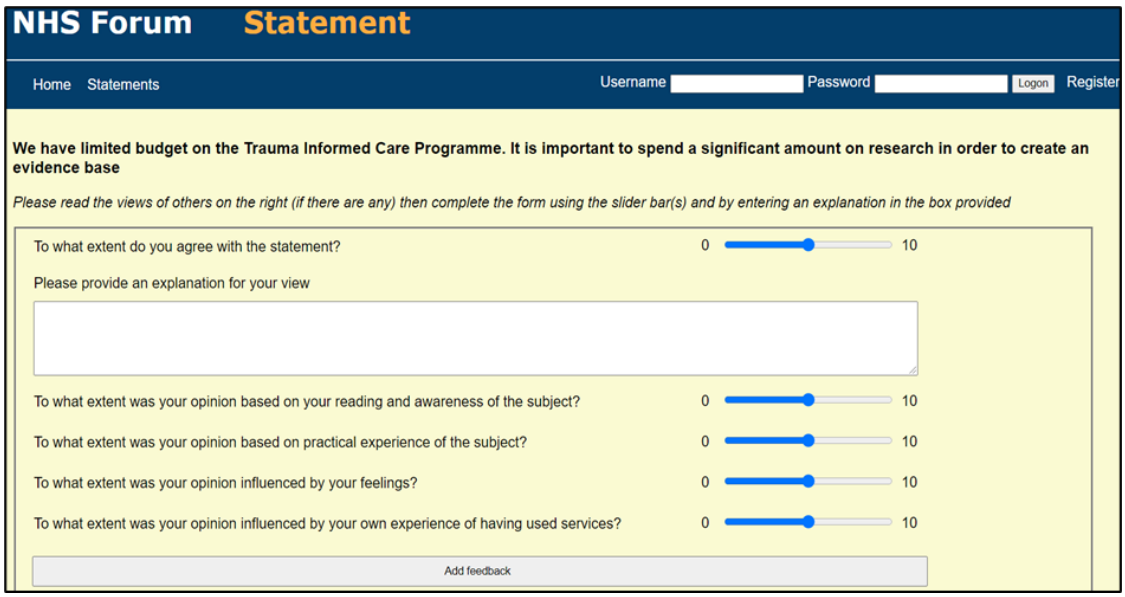

Figure 3 The view of the ODS screen to express an opinion the first time the user sees a given statement.

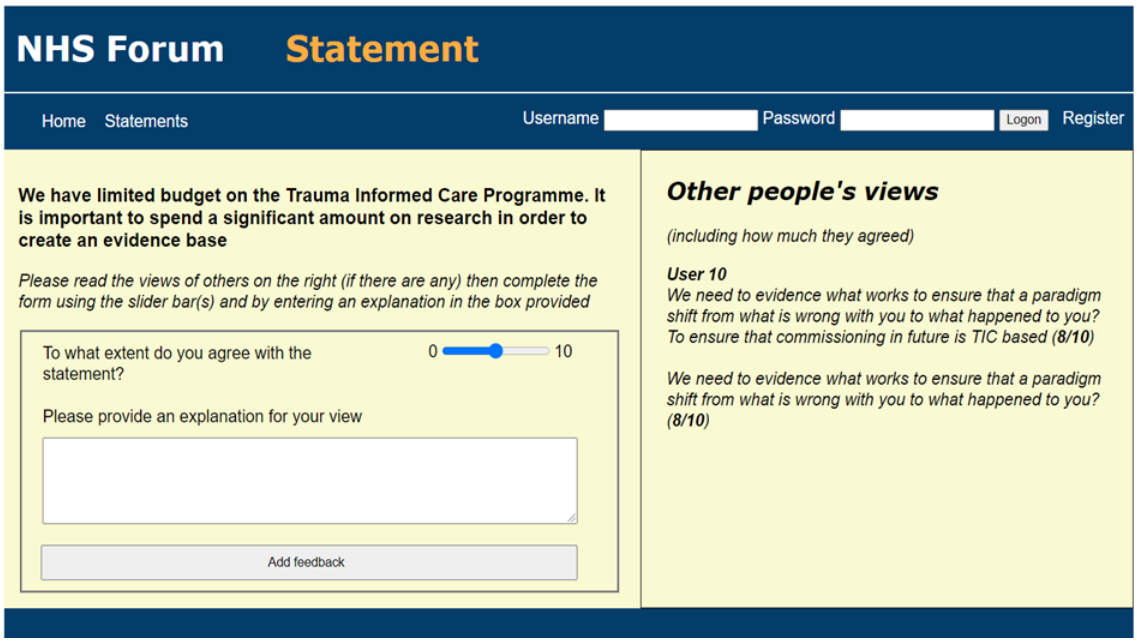

Figure 4 The view of the ODS screen to express an opinion on subsequent occasions, including two opinions and their ratings from another user in the network.

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