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Difficult to Change Knowledge: Explanations and Interventions

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It is readily clear to the participants at this conference that misconceptions in science and mathematics are ubiquitous. They can be documented in almost every subfield of science and many commonly share one important feature in that they are difficult to modify. The purpose of this paper is to explore this issue of resistance to change by looking at what factors underlie this resistance and to investigate whether such resistance to change is a common feature of human functioning in areas other than scientific reasoning. Such an investigation may provide insight in to how to modify such misconceptions. We begin our exploration with an initial look at the work on the resistance to change of scientific misconceptions.

Scientific Misconceptions

The research literature on the learning of scientific concepts has established the fact that students (including both adults and children) begin (and often end) their scientific training with conceptions that differ in fundamental ways from experts in the various scientific fields. This is the case in fields as diverse as physics (Dykstra, Boyle, and Monarch, 1992), astronomy (Vosnaidou and Brewer, 1992), chemistry (Schmidt, 1992), mathematics (Leinhardt,

Zaslavsky, & Stein, 1990), and biology (Westbrook & Marek, 1992). An extensive literature has grown in attempting to explain why these scientific misconceptions appear so resilient and difficult to change. The large majority of this work has centered on the kinds of knowledge structures children and adults have about scientific concepts and the particular features of these structures which make them resistant to instructional intervention.

Some recent analyses of the abundant work in this area are beginning to demonstrate a reasonably small and common set of factors which are involved in difficult to change knowledge situations. Not all of these factors occur in every scientific misconception, a fact which may explain why interventions which are successful in one setting have little, if any, impact on another. We would like to briefly describe each of these factors.

First, some misconceptions find continual reinforcement in everyday settings. For example, a frequently investigated misconception involves the concept of force in physics (Chi, Feltovich, & Glaser, 1981). This concept often seems to be interpreted according to a naive theory which assumes that motion implies a force. According to this view, an object in motion will slow down unless a force is continually applied to it. Clement (1982) demonstrates several different settings in which this interpretation arises. In some of these settings students do not recognize the existence of the hidden force of friction. Friction results in observations of object movement which are consistent with the student's naive theory. Thus the student's misconception is continually reinforced by his/her numerous encounters with objects in everyday settings. Chinn and Brewer (1993) appear to be referring to a similar factor when they describe "entrenched" theories.

Second, Chi (1992) convincingly argues that students sometimes categorize important scientific concepts in incorrect ontological categories. We may use the concept of force once again to illustrate. An analysis of student's conceptions illustrate that some students categorize force in the ontological category of "matter." That is, force has the properties of "having substance" and "is capable of being dissipated." However, the physicists's conception of

force is not as "matter" but is rather as an "event." That is, force has properties such as "duration" and "has a beginning and an end." When students misunderstand key concepts in such fundamental ways, they may find it very difficult to even make sense of certain statements made by a teacher. In these cases an instructor's comments may simply be ignored. It is important to realize that it may be the lack of experience with certain settings as described in the first point that leads to such fundamental misattributions.

Third, substantial evidence suggests that individuals will not give up an existing belief, hypothesis, or theory unless they have (or can generate) some plausible alternative (Chinn & Brewer, 1993). Thagard and Nowak (1990), for example, discuss how the theory of continental drift received little support until a plausible hypothesis was put forward which could explain how such drift could occur. Chinn and Brewer (1993) review several other examples in which the existence of a plausible alternative is crucial before existing conceptions will be given up.

Fourth, motivational factors also appear to play key roles in knowledge change. If a misconception is held in an area in which students have little interest , they will be unlikely to invest the cognitive resources necessary to reconceptualize the area.

Fifth, students must have some modest level of background knowledge in an area to allow them to begin consideration of alternative interpretations. Strike and Posner (1985), for example, argue that some background knowledge is crucial for engaging in instructional activities leading to knowledge change.

This listing of underlying factors involved in resistance to change of scientific misconceptions is not exhaustive, but it does help point to some key issues that educators must keep in mind when dealing with scientific misconceptions. There may well be other key underlying factors that must be considered and we need to keep actively searching for such factors.

However, it is crucial that in our efforts to understand the resilience of scientific misconceptions that we not fall prey to hidden assumptions which limit out thinking and subsequently our search. It is worthwhile to step back and ask what assumption underlie the

current work on misconceptions. Our analysis suggests that researchers are making two fundamental assumptions that may be having a negative effect on the work on scientific misconceptions.

First, the work on scientific misconceptions appears to be following the same set of framing assumptions about human cognition that have dominated the study of human cognition for the last couple of decades. These framing assumptions are clearly described by Greeno (1989). We don't have time to deal with all of them here, but one is particularly pertinent to our topic today. This is the assumption that cognition goes on inside the individual's head. Greeno notes that modern cognitive psychology places the locus of such concepts as intelligence in the individual's head. Thus, we say that Jill is intelligent but Jack isn't. In this manner intelligence is made to reside in the person. A number of researchers are beginning to call this assumption into question. Based on the work of such individuals as Vygotsky, researchers are reframing concepts like intelligence to include the individual interacting with his/her environment. This view is referred to as "situated cognition." Thus, individuals are found to function differentially depending upon the amount and type of environmental support they receive. A child who seems to function poorly in one setting may function remarkably well in another.

We think researchers on scientific misconceptions function under this same framing assumption. That is, misconceptions are in the students' heads and we have focused our attention on the character of those misconceptions and how to change them. But in a real sense individuals who hold certain scientific misconceptions function remarkably well in a number of environmental settings. We need to explore these settings carefully if we are to understand the resilience of misconceptions. There is some recent work that is developing this viewpoint. We note Linder's interesting article titled "A challenge to conceptual change" in Science Education (Linder, 1993). This viewpoint offers great potential but we will not develop that argument further in this talk.

There is a second fundamental assumption that we think also underlies the work on scientific misconceptions. This is the assumption that the resilience of these misconceptions is due solely

(or at least primarily) to incorrect knowledge structures. Almost universally researchers on scientific misconceptions discuss issues of errant knowledge structures (or incomplete ones, or pieces of knowledge structures (DiSessa, 1988)) and the bulk of the theories wrestle with how to modify these errant structures. It is, of course, possible that the knowledge structures are fine, but that they are being used inappropriately or ineffectively. This could occur for many reasons including the automatic activation of the wrong portion of a knowledge structure or the activation of the wrong structure for a particular setting. Although it is unlikely that such an explanation could account for all the findings on scientific misconceptions, it might be a major contributing factor, one, in fact, which might fit well with the concept of situated cognition.

This brief review of the work on scientific misconceptions suggests that there may be a few underlying reasons which make misconceptions so difficult to change. This conclusion is drawn from looking at research which focuses directly on when and where scientific misconceptions arise. We may also gain insight into these misconceptions by investigating other areas of human functioning, if any, where maladaptive behavior persists in the face of attempts to change or modify it. Such an investigation may provide fresh insight into this peculiar resistance to change. We investigate three such areas in the remainder of this talk.`

Human Judgment and Decision Making

In the human judgment and decision making area individuals demonstrate suboptimal behavior in a number of different tasks. This suboptimal behavior usually takes the form of decision making processes or heuristics that consistently result in judgment errors of one type of another. These suboptimal behaviors are frequently referred to as biases. Some examples of these biases include the following: a. hindsight bias (in which individuals exaggerate the likelihood that they would have been able to predict an event before the event occurred), b. confirmation bias (in which individuals selectively search, recollect, or assimilate information in a manner

that lends spurious support to a particular hypothesis which is being considered (Arkes, 1992)), c. preference for clinical versus actuarial judgment methods (Dawes, Faust, & Meehl, 1989), d. overconfidence (in which individuals exhibit an unwarranted over confidence in their judgments), e. representativeness (in which individuals judge probabilities based on how similar or representative they are of some situation or person), and f. sunk cost effect (in which the judgments of individuals are influenced by how many resources have been invested in a particular action).

Efforts to modify or alter these errant decision making processes, referred to as efforts to debias, have shown these processes to be very resilient to change. Fischoff (1982), for example, in reviewing techniques aimed at debiasing hindsight bias noted that many different techniques had been tried but that few of these techniques successfully reduced hindsight bias and none eliminated it. Similarly, Fischoff (1982) noted that overconfidence is relatively resistant to modification by a variety of manipulations. Dawes, Faust, and Meehl (1989) reviewed research on the use of clinical versus actuarial judgment which demonstrates a consistently better outcome on decisions based on actuarial judgment methods than clinical ones in several domains. For example, Goldberg (1965,1968) demonstrated that a relatively simple actuarial rule for distinguishing between neurosis and psychosis based on the Minnesota Multiphasic Personality Inventory correctly judged 70% of a large sample of MMPIs for this distinction. In contrast, the average performance of a set of 29 judges was 62% and the single best judge was 67%. Despite this type of evidence, professionals in various areas are very resistant to applying actuarial methods and list any number of reasons for their reluctance to adopt actuarial methods (Dawes, Faust, & Meehl, 1989).

Why are these apparently error prone decision making processes so resistant to modification? Arkes (1992) provides a very insightful analysis of these judgmental errors. The character of his argument may provide useful observation into the resilience of scientific misconceptions. Arkes notes that most, if not all, of the error prone decision making processes are built upon highly beneficial cognitive

adaptations to various demands upon humans. However, these successful adaptations can have costs in certain settings (as do most biological adaptations). Arkes, for example, notes that the beneficial biological adaptation to an upright stance in humans (making the hands free for tool use) has costs of higher levels of lower back pains. Similarly the cognitive benefits of developing expertise in an area which allows individuals to perform well in many relevant situations, are linked with unjustified inferences in some settings or contexts. Arkes extends his analysis to suggest that there appears to be three distinct types of judgment errors that show up across the wide ranging decision making biases noted above. We will take time here to briefly describe two of these error types.

Arkes first describes what he labels strategy based errors. These are errors in which relatively quick and dirty strategies are employed to solve a problem. The quickness of the strategies is a benefit; its dirtiness is a liability leading to more errors than a slow meticulous strategy. Arkes notes than in many settings where the cost of errors is small the use of such strategies is highly adaptive in that there is a great savings in cognitive effort. If such a reason lies behind the consistent errors made in some decision making settings, any manipulation which increases the motivation to perform well should eliminate or reduce these kinds of errors and the evidence supports this analysis.

In contrast to strategy based errors are association based judgment errors. These are errors in which activation of one idea in memory automatically triggers other associated ideas which may channel processing in malady ways in certain specified tasks. For example, when individuals have access to the final outcome of an event such as a medical diagnosis, this information automatically triggers related items in semantic memory. This higher level of activation which is often not under conscious control raises the likelihood that this information will receive higher weighting when making judgments about whether the event would have been predicted beforehand. That is the potential foundation of hindsight bias. Since such associative activation is typically not under conscious control, it is very resilient to many debiasing techniques. Certainly efforts to

increase motivation for correct answers is not going to stop automatic activation from proceeding.

Arkes' insightful analysis of the resilience of decision making errors to debiasing thus provides two potentially useful observations about scientific misconceptions. First, we need to explore the possibility that scientific misconceptions are the consequences of generally beneficial cognitive adaptations which are inappropriate for certain environmental situations. Second, we may find that different kinds of explanations lie behind different kinds of misconceptions. A detailed understanding of these explanations could prove crucial for establishing effective interventions.

Psychotherapy

The field of psychotherapy is fundamentally rooted in bringing about change in individuals. Over the long history of the field many different theoretical approaches to understanding and bringing about change have been proposed. Over the past 15 years psychotherapies based specifically in bringing about cognitive changes have become very popular (Brewin, 1989). Dobson (1988), for example, identifies over 20 different types of cognitive-behavioral therapies differing in their rationale and hypothesized processes.

A common thread running through much of the research literature on psychotherapy involves the concept of resistance, specifically resistance to change. When first encountered, the notion of resistance seems puzzling and counterintuitive. Patients have presented themselves to a therapist with various symptoms and behaviors which are markedly disrupting their lives. These symptoms may run anywhere from depressive episodes to suicidal tendencies. Yet, as Bugental (1984) notes, the very "patient who comes seeking desperately for help soon bends every effort to defeat help being given." (p 543). Although the concept of resistance predates Freud and has been a point of debate among various theoretical views in the twentieth century, Mahoney (1991) argues that the concept recently has become more accepted and in some cases welcomed in the field of psychology. Mahoney (1991) reviews five current theories of resistance, all of which are of some interest to our concerns. For the present we wish to emphasize one of the current views, self-protective theory, which seems especially pertinent to the issues we are wrestling with.

Self-protective theory emphasizes the healthy caution about undergoing change that might challenge the integrity, coherence, and even viability of a living system (Mahoney, 1991). In essence, humans appear to be reluctant to change too much too quickly and to carry out change which alters their basic understanding of themselves and their worlds (Mahoney, 1991). This aversion to change is sometimes especially poignant when individuals are found to cling to behaviors that are clearly negative in their consequences for the individual.

Firestone (1984), for example, comments about a patient who uses a strategy of self-hatred to organize her life. At one point in therapy she senses she is losing her ability to hang on to this strategy and comments, "It's like the world falls in on me, I feel like screaming down the hall and doing anything - banging my head against the wall - to get back my "life force" of self-hatred."

We need to explore further this belief that resistance to change may have healthy consequences for individuals to see if it has relevance for understanding difficult to change scientific misconceptions. Important in understanding this perspective is the belief that humans construct interpretations of themselves and their worlds. These constructions according to Mahoney (1990) include four core themes about one's identity (that is, one's sense of self), order (one's sense of meaning, truth, and reality in the world), value (one's feelings and emotions), and power (one's sense of competence and control). These constructions allow individuals to interact with the world in some orderly fashion. From another perspective the core constructions that a particular individual has fashioned may seem maladaptive and even self-destructive. However, as Bugental notes losing what order one has even though it be small is terrifying. Mahoney (1990) notes that he frequently counsels clients that as they begin making changes that are seen as desirable, they may feel ambivalent because they may see themselves in danger of losing an old self or becoming confused about who they are. Importantly Mahoney notes that significant and long lasting changes in personal identity take place over a long time frame, measured typically in months or even years.

It is clear then that changes in certain core constructions have major emotional implications, implications which increase resistance to change. We must at least ask ourselves, do scientific misconceptions ever hold this type of deep core belief. Our first judgment may be that this is unlikely but key scientific conceptions can impact on deeply held values (e.g., religious or ethical concerns) and might also relate to one's sense of self (e.g., I am scientifically incompetent).

Therapeutic change may be useful in understanding scientific misconceptions in another manner. Mahoney (1991) and Brewin (1989) both suggest that a detailed understanding of psychotherapy and psychotherapeutic change necessitates dealing with nonconscious and automated behaviors. Mahoney, for example, suggests that many of the core constructions which individuals create operate below the conscious level and are thus generally inaccessible to conscious intervention. Brewin suggests that nonconscious situational memories play important roles in emotional and cognitive processing. Such processes are carried out very rapidly, are relatively inflexible, and are difficult to modify. Thus, just as we saw in the judgment and decision making work, nonconscious and automated processes may partially account for the apparent resistance of knowledge structures to modification and change.

Finally, there is one last observation about knowledge change which arises from the literature on psychotherapy. Mahoney (1991) notes that clients in psychotherapy commonly report their experience in terms of the quality of their emotional bond with their therapist. Mahoney suggests that this bond seems to provide clients with a secure base from which they can explore potential change in their self construction. This phenomenon seems related to reported findings in other areas of knowledge change that individuals need to have alternative hypotheses available before giving up or casting aside current hypotheses which are ineffective.

In summary, the work on psychotherapeutic change provides us with three useful observations about scientific misconceptions. First, we need to entertain the idea that resistance to change may be a natural and healthy process in which the individual proceeds cautiously in altering well established beliefs which have allowed the individual to function quite adaptively in his/her world. Second, nonconscious and automated processes may be crucially involved in scientific reasoning. Key situational variables may activate ideas and concepts which make certain kinds of reasoning more likely to occur than others. The fact that they are nonconscious and automated makes them very difficult to modify. Finally, just as clients in therapy need a secure base from which to explore new hypotheses

about their view of the world, individuals facing difficult scientific tasks need tenable new hypotheses (or at least strategies to generate such hypotheses) before they are likely to cast off currently held views.

Attitude Change

The attitudes which individuals hold regarding people, places, and events play a crucial role in social interactions among people. For example, how we perceive and conceptualize individuals (he is a black football player) or events (it is a meeting of used car salesmen) influences our behaviors and actions in social settings. A perplexing issue about such attitudes is that they are remarkably resistant to change (Eagly and Chaiken, 1993). Social psychologists, educators and even governmental agencies have employed various means in attempts to alter attitudes. Educators, for example, have attempted to change children's attitudes about minority groups and governmental agencies have attempted to alter attitudes about AIDS patients. In many cases these attempts end in failure. Why are attitudes so resistant to modification?

Eagly and Chaiken (93) review the extensive research and theory about resistance to change in people's attitudes. As in other areas of resistance to change, the first approach to explaining resistance is to claim that appropriate interventions have not been used or the intervention attempts have been poorly designed. However, the consistency of the results soon suggests that something more pervasive than experimental error is at work. As in both the decision making and psychotherapeutic domains a deeper level of analysis of resistance suggests a potential positive aspect of resistance to modification. As Eagly and Chaiken note "The idea that people ordinarily would be willing to change their attitudes is not plausible when analyzed with care. Complete and continuous openness to new influences would leave the individual with a constantly shifting view of reality..... attitudes allow people to anticipate events and to cope easily and effectively with events that occur repeatedly. Although attitudes reflecting substantial past experience may be maladaptive in a changing environment, they ordinarily serve people quite well" (p. 559-560). Thus we again see that resistance to change may be indicative of a generally adaptive manner of interacting with the environment that becomes maladaptive only in particular contexts or settings.

Other approaches to understanding resistance to attitude change suggest some underlying reasons which make attitudes resistant. Generally, these reasons can be categorized under two major headings - motivational and cognitive explanations. Motivational explanations take several forms but they have in common that attitude change can result in emotional trauma or stress for individuals. This stress may arise because a person holds a particularly strong belief in some attitude and that modifying this belief has a major emotional impact. Similarly some attitudes may relate to issues that are heavily emotionally laden (e.g., sexual or aggressive urges) which may lead individuals to avoid even discussing these issues let alone to change their stance. Finally, motivational resistance to change may arise for broad based issues that are not related to any particular attitude, but to attitudes in general. Eagly and Chaiken note that attitude change may relate to the concern for preservation of freedom. Changing our attitudes, for example, can threaten our freedom to believe or do what we desire. Social psychologists refer to this motivated resistance to loss or threatened freedom as reactance. There has been extensive empirical research on reactance theory. This research, for example, demonstrates that obvious, high pressure techniques aimed at changing attitudes tend to foster resistance to persuasion.

Cognitive explanations for resistance to change frequently take the form that attitudes become embedded in elaborate cognitive structures. These structures link particular attitudes to particular beliefs, emotions and behaviors as well as to other attitudes (e.g., a negative attitude toward homosexuals, may be linked to a negative attitude toward people with AIDS). Resistance to change in an attitude then may be linked to a type of domino principle (Eagly and Chaiken, 1993) in which the change in one attitude necessitates a change in many other attitudes and beliefs. Such a situation could be highly disruptive to the individual and may lead to resistance to change. Empirical studies of such attitude embeddedness have found support that extensive interlinking of attitudes does indeed lead to greater resistance to change (Ostrom and Brock, 1968).

The work on attitude change provides us with some observations of value in understanding resistance to change in scientific misconceptions. First, resistance to change of attitudes may have a generally positive effect on person-environment interaction. The persistence of attitudes may provide a stable base from which individuals can construct a working model of their environment. Do scientific misconceptions suggest an underlying model which allows for effective environmental interaction? Second, both motivational and cognitive issues arise which foster resistance. Motivationally, resistance allows individuals to avoid emotionally laden issues which may disrupt cognitive functioning. Cognitively, resistance reduces the extensive overall cognitive modification necessary if certain attitudes are altered. Again we need to consider whether changing underlying scientific beliefs could result in significant emotional impact or would necessitate substantial overall modification of major underlying cognitive structures.

Conclusion

This brief overview of research and theorizing about difficult to change but maladaptive beliefs and behaviors suggests that the resistance to change found in scientific misconceptions is not an uncommon phenomenon. Some common themes run through all this work on resistant behavior and it is useful for those of us interested in scientific misconceptions to consider these common themes. We hope they provide a framework upon which to build an intervention strategy.

First, a major theme which runs across a number of these areas is that resistance to change may have important positive benefits for the individual. Stable, well articulated knowledge structures provide people with the ability to anticipate and cope easily with a broad range of environmental events. We see this in responding socially to individuals, in making judgments and in adapting to psychological stress. It is important to remember that these generally useful knowledge structures work in many settings, but not in all. Thus, if we focus only on when these structures fail and show

negative consequences (e.g., hindsight bias, negative stereotypes) we may fail to see their generally adaptive character. A similar situation might occur with scientific misconceptions. Those of us interested in scientific misconceptions need to determine if these misconceptions are examples of very adaptive strategies which fail in some particular contexts. If this is the case, an important issue for researchers on scientific misconceptions is to carefully investigate the contexts in which misconceptions arise. An understanding of these contexts could be fundamental to developing a sound intervention approach.

The second major theme which underlies the work on difficult to change behavior is that there exists a relatively small set of specific reasons which crop up in resistant to change situations. Understanding these specific reasons is crucial if we are to build effective intervention strategies. We won't reiterate all of them here but we will mention a few crucial ones which show up in several different areas. First, some behavior is resistant to change because it is extensively reinforced (that is, deeply entrenched). This is seen in almost every area of resistance to change. Scientific beliefs which function well in everyday settings, or attitudes which have been reinforced for years in a biased home are difficult to modify. We must find systematic ways to provide long term alternative experiences if we are to be successful

Second, a fundamental principle involved in change appears to be the necessity of having available alternative hypotheses if change is to occur. A consistent pattern found in all the areas reviewed in this paper (e.g., confirmation bias in decision making; changes in maladaptive personal behaviors) is that having a hypothesis from which we can operate is absolutely crucial. Thus, using a maladaptive strategy seems preferable to having no strategy. We must insure that science students have access to understandable alternative hypotheses about the world around them.

Third, individuals need to have a basic understanding of the new hypotheses and their underlying assumptions. For example, if students do not understand the character of "events" and that force can be conceived as an "event," instructional strategies are unlikely

to work. Building this background knowledge is fundamental to effective intervention.

Fourth, individuals must be sufficiently motivated to change if change is to occur. The commonly noted observation that people must want to change (e.g., want to cease alcohol abuse or cigarette smoking) if intervention techniques are to work is likely similar to the student who must want to understand a scientific principle in order to learn it. Such motivational issues are an important ingredient to intervention procedures in all areas of difficult to change knowledge.

Finally, it is clear that emotional issues play key roles in several areas of resistant to change behavior. This emotion might arise because some fundamental beliefs are challenged or because hypothesized changes will necessitate a complete restructuring of one's underlying knowledge in a field. Social and clinical psychologists have wrestled with this dilemma more than have educators. However, we should at least consider the role which emotional issues have for change in scientific beliefs.

The third major theme which runs through the research on resistant to change behavior is that we must realize that resistant behavior may not only arise because individuals hold the wrong theory. It may be that the knowledge structure which the individual holds is fine, but this structure is being inappropriately used. This issue arises most clearly in the decision making and therapeutic areas, but it may be equally applicable in understanding scientific misconceptions. If certain contextual events automatically trigger portions of a knowledge structure, the individual may be led down an inappropriate pathway of thought. If this is the case, intervention may need to be less aimed at modifying the knowledge structure as in modifying the contextual setting which triggers the structure.

We hope this broader view of resistant to change behavior provides insight into a better understanding of scientific misconceptions. It is difficult to imagine that widely held scientific misconceptions have no link to beneficial cognitive adaptations. At least, that is not the pattern in other difficult to change behaviors.

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