“Cognitive science should be more than just people from different fields having lunch together to chat about the mind.” (Thagard, 1996, p. 7)

Abstract

Interdisciplinarity – the integration of concepts and epistemologies from different disciplines – is often considered highly desirable as a way of gaining insight and furthering our understanding of a research problem.

Introduction

There is a widespread view that interdisciplinary research is a good thing. By ‘interdisciplinarity’ is usually meant something like: the emergence of insight and understanding of a problem domain through the integration or derivation of different concepts, methods and epistemologies from different disciplines in a novel way. However, it is also widely believed that ‘true’ interdisciplinarity is very difficult to achieve and, more often than not, remains an elusive goal. In practice, many self-styled interdisciplinary enterprises actually work at the level of being multidisciplinary (or pluridisciplinary): where a group of researchers from different disciplines cooperate by working together on the same problem towards a common goal, but continue to do so using theories, tools, and methods from their own discipline, and occasionally using the output from each other’s work. They remain, however, essentially within the boundaries of their own disciplines both in terms of their working practices and with respect to the outcomes of contemporary cognitive science. Finally

theoretical frameworks coming from different disciplines. An example is ecological economics where scientific aspects of ecological events have been integrated with their social consequences in order to make objective assessments of ecological aspects. By contrast, multidisciplinary approaches are assumed to evolve *new understanding* through *adapting and modifying* existing concepts, methods and theoretical frameworks within a discipline and occasionally borrowing ideas from others. Here we woulfc 12 0 0 -12 34355.(

environment and social structures. The main reason behind this obduracy is that each views the other as self evident and hence simply takes it for granted (Cicourel, 1995). For example, in one of our recognize the need for a change of tactic from the multidisplinary approach?

One way forward here is to identify what the impetus has been in cases where we can see an area that clearly demands input from more than one conventionally-defined discipline and where no one alone has a comprehensive set of theoretical frameworks or methodological tools to deal with it. For convenience we divide these into cases where an existing problem has simply seemed too large for a single discipline to cope with by itself and those where something external to the disciplines has forced itself on their attention. Here we shall consider examples of both of these: firstly a program to develop a more comprehensive account of cognitive science and secondly, the evolution of two related applied fields – Human Computer Interaction (HCI) and Computer Supported Cooperative Work (CSCW).

Interdisciplinarity: as an ideal

Cognitive Science is a classic example of the emergence of a new field that set itself up to be truly

In the beginning the disciplines that were brought in to develop the new field of cognitive science were cognitive psychology, artificial intelligence (computer science), linguistics, philosophy and neuroscience (Green, et al, 1996; Johnson-Laird, 1988; Thagard, 1996; Von Eckardt, 1993). Since then a whole host of others have been identified as important contributors, including anthropology, sociology, engineering, HCI and education (Schunn et al, 1998). With so many potential collaborators, the stage seemed set for a range of combined efforts to emerge. Indeed, a number of such collaborations have been reported throughout the potted history of cognitive science. For example, Schunn et al (1998) cite the early collaborative efforts of Simon, Newell and Shaw's when building their logic theorist program. It is claimed that their work involved combining ideas from economics, psychology, mathematics and computer science. Their output was a computer program that arguably had more explanatory power than what would have evolved from within a single discipline. Kosslyn's work on mental imagery is also viewed as a paradigmatic example of interdisciplinary research – whereby his early empirical research from the 80s, on how mental images work, spurred a number of other researchers from different disciplines to extend his research in relation to their own models, perspectives and empirical findings. For example, Farah (1984) extended Kosslyn's work into the area of imagery deficits in neurologically impaired people, developing a further explanation of the role of imagery in cognition by identifying its physiological localization (Von Eckardt, 1993). More recently, Green et al (1996) have pointed out how neuropsychological research (especially on brain damaged patients) has provided insight for models of cognitive functioning, and in so doing they claim enabling a better integration of biological and cognitive accounts. Schunn et al ET Q q 1 78 0 0 -1 18 824 c8t1 0 T Q 0.012

Whilst these examples have been set up as paradigmatic of interdisciplinary research in cognitive science, it is actually quite difficult to determine what form any level of shared understanding between the different parties with regard to the referents and terms each is using. Such frustrations can leave researchers wondering whether the costs involved in such ventures outweigh the benefits of doing so. For example, in their survey of multidisciplinary research in cognitive science, Schunn et al (1998) found that multi disciplinary collaborations were not rated as being any more successful than mono-disciplinary collaborations. One of the biggest complaints was that multi collaborations generated too many different ideas. Similarly, Scaife et al (1994) note that one of the key problems arising from their collaborative research project, with partners from cognitive psychology, design and computer science, respectively, was the difficulty of communicating and knowing what to do with the different ideas generated between them.

As mentioned previously we are trying to identify occasions when there has been an effective impetus for interdisciplinary research to break out and make any headway. Cognitive develop an applied cognitive science and secondly, a way of overcoming the deficiencies of a disembodied theory of cognition.

The need for an applied cognitive science stems from a recognition that there are "massive gaps in our scientific knowledge... because there has not been sufficient study of real, naturally occurring behavior" (Norman, 1990, p.4). We shall come back to this later but first we shall briefly consider the external (to cognitive science itself) push for disciplinary collaboration generated by technological advances in computing and telecommunication technologies. These have provided us with much scope for new forms of collaboration, communication and computational support including the ability to manipulate and interact with information in a multitude of ways, together with interacting with each other in remote and virtual spaces. In turn there has been a growing expectation within the system design community that cognitive science should and could have practical application for understanding these developments. Existing tools, theories and methods from within the contributing disciplines, especially cognitive psychology, however, have proven to be largely disappointing, being inappropriate and largely unusable (e.g. see Barnard, 1991; Rogers, 2000). Here, therefore, was an opportunity for a breakaway group of researchers, frustrated by the limits of their existing disciplinary knowledge, to come together and create a new field that could evolve new knowledge and methods that could be applied to practical problems.

Interdisciplinarity: forming applied fields

The perceived need for a new form of interdisciplinarity was very much the driving force behind the emergence of two and computer science to design more effective human-computer interfaces for single user applications. In CSCW, the goal shifted towards bridging the gap between the social sciences and computer science in order to develop more usable and useful collaborative computer systems for multi-user settings.

What we can see, however, from these kinds of more applied endeavors that have tried to attain interdisciplinarity, is that the process is very much an uphill struggle to break away from a multidisciplinary mindset. The jury is still out as to whether either HCI or CSCW have in fact been able to achieve any significant level of interdisciplinarity. In a critique of the interdisciplinary accomplishments of the two fields, Bannon (1992) argues that whilst there have been several laudable attempts to develop new frameworks that allow for a family of theories and different concepts to be incorporated (e.g. Kuutti and Bannon, 1993), there has yet to be any convincing research projects reported, where different disciplines have genuinely wedded together, and made mappings across concepts, that have resulted in the development of a common unified theory. However, rather than see this as a failing of such enterprises, he argues that the goal of true interdisciplinarity in these contexts is fundamentally flawed since the world views, backgrounds, research traditions, perspectives, etc. of each of the contributing disciplines are often so different that they are simply not commensurable with each other. Attempts to build such hybrid frameworks are likely to come up against this dilemma. Recent examples like Mantovani's (1996) model of social context – where he takes a wide range of concepts and research findings from the social and the cognitive sciences, combining top-down with bottom-up approaches for the purpose of analyzing social norms and mental models together – are witness to this. Different terms, ontologies and methods are mixed together, making it difficult to make sense or apply together the various strands and levels presented in the model of isolating and controlling it in a laboratory setting. The reason for this is based on a growing acknowledgement that the assumptions behind lab-based cognition do not necessarily hold true in the real world:

"In the tradition of disembodied intellect, the person simply cogitates. The assumption is that the person starts with full and complete knowledge of the world-state relevant to the issue at hand, selects a course of action, then plans and executes it. I argue that this is neither what people do nor is it possible." (Norman, 1990, p.6)

Thus, although a psychologist can try to study the behavior of subjects in an experimental lab – observing them interacting with environments that embody knowledge they can control – they cannot understand the behavior of, say, operators in a control room since they cannot extrapolate from the former setting to the latter. This is because they have no real understanding of the knowledge embodied in the external representations that the operators create and use in their work. The continuous interplay of internal and external representations is completely out of the psychologist's range of investigation unless they begin to study, together with engineers, physicists and others, the way in which artifacts are actually used in the control room work.

Several researchers within cognitive science have taken up the challenge of studying cognition as practiced in different cultural settings, providing alternative explanations that reconceptualise cognition as situated within its cultural, social and environmental context (e.g. see special issue of Cognitive Science, 1993, on situated cognition). Such attempts have tended to adapt and assimilate concepts from other fields to contextualise their existing theories about cognition. As such the process of evolving a new understanding arises through local adaptation. A more extensive form of adaptation is to seek ways of developing a new understanding by reconceptualising a domain area using a new unit of analysis. An example of this more global strategy is Hutchins (1995) distributed cognition approach, where he broadened the mainstream cognitive science unit of analysis – which focuses exclusively on the properties and processes inside the mind of a single person – to one which extends to a family of cognitive systems. As well as continuing to allow for a unit of systems is that it can reveal cognitive properties that cannot be reduced

– where novel outputs are yielded through different individuals coming together and working as a team – is generally viewed as desirable. To achieve this, however, requires the various individuals becoming more open to new ideas and ways of communicating with each other. It also means learning about and accepting the other discipline's way of working. It is becoming increasingly apparent, however, that to enable this kind of mutual understanding to occur also requires some kind of lingua franca (Green et al, 1996). In particular, what is needed is a way of representing and talking about new concepts, that can be readily exchanged between the participating disciplines.

A good example of where researchers from different disciplines can work together and develop a new method is a project carried out by a team of sociologists and software engineers at Lancaster University (Sommerville et al, 1993). They were interested in developing systems for multiple end-users, in particular, for the domain of air traffic control. Their starting point was to acknowledge that the conventional software engineering approaches to requirements capture and analysis were inappropriate in their current form for use in the design of these kinds of collaborative systems. This was because the software engineering methods – developed originally to support formal structures – were seen as being unable to cope with the dynamic and informal ways of working which groups of people invariably adopt in different work settings. An important step for the group was then to determine how groups actually work together and to then work out a way of using this information to software engineers could more easily relate to and use when designing software.

However there are a number

comment on. This is a separate problem from that of understanding terminologies across disciplines.

What the above examples demonstrate, therefore, is that even multidisciplinarity in an applied domain can be highly problematic. It suggests that for multidisciplinary teams to have the best chance of succeeding then both the nature of the problem space has to be clear to all and that all parties concerned are prepared to act upon it by being willing to change how they do their research. This may mean taking a radical departure from what is prescribed in their parent discipline, but in breaking away novel solutions can emerge.

Interdisciplinarity as emergent: Understanding how external representations work in relation to human cognition

We have seen something of the problems (and opportunities) that can occur in the process of collaboration and communication in multidisciplinary team work. But in the cases we've discussed the aim was to produce a new artifact. What occurs when the goal is the more nebulous one of 'promoting understanding' or 'evolving new ideas' within a domain? We can examine something of this process by looking at our own efforts with a particular research problem: the role of external representations in cognition. We consider ourselves as cognitive scientists and so we shall briefly present this work through the lens of Norman's (1980, 1990) desiderata for cognitive science which we have quoted previously. Amongst other things, it will be recalled, he argued for the necessity of understanding interactions between issues and for a more applied and situated orientation. One question here is whether, in so doing, we can therefore allow ourselves the label of interdisciplinarists?

The impetus for our research was the lack of any generalisable theories in this domain. By this we mean explanations that could enlighten us on how people interact with different kinds of external representations – be they diagrams, animations, multimedia or virtual reality – for a variety of cognitive activities (e.g. learning, problem-solving, reasoning). In an extensive review of the literature, including cognitive science, education, psychology, instructional science, HCI and art history, we discovered a fragmented and poorly understood account of how graphical representations work, thereby exposing a number of assumptions and fallacies (see Scaife and Rogers, 1996). The main reasons for this state of affairs seemed to be twofold. Firstly prior empirical cognitive behavior (e.g. see special edition of the journal of Cognitive Science, 1993). A few researchers had also specifically been giving external representations a more central functional role in relation to internal cognitive mechanisms (e.g. Cox and Brna, 1994; Kirsch and Maglio, 1994; Larkin 1992; Norman, 1993; Zhang and Norman, 1994). Others, too, had begun putting forward alternative concepts like re-representation and expressiveness – originating from philosophy and logic – to explain why certain graphical representations were more effective

At the highest conceptual level, cognitive interactivity refers to the interaction

Conclusion

So, are we inter-disciplinary? Well we're not really sure how to answer this and whether it is really important to do so.

psychology at the human-computer interface (pp. 103-127), New York: Cambridge University Press.

Bauer, M.I., & Johnson-Laird, P.N. (1993). How diagrams can improve reasoning. *Psychological Science,* 4, 372-378.

Brown, G.D.A. (1990) Cognitive Science and its relation to psychology. *The Psychologist,* 8, 339-343.

Cognitive Science, (1993). 17(1) Special Issue: Situated action.

Cicourel, A. V. (1995) Cognition and cultural belief. In P. Baumgartner and S. Payr, (eds.), *Speaking minds: Interviews with twenty eminent cognitive scientists.* Princeton Academic Press, NJ. pp. 47-58.

Cox, R. & Brna, P. (1994). Supporting the use of external representations in problem-solving: the need for flexible learning environments. *(Research Paper No. 686A)* Edinburgh: Dept. of AI, University of Edinburgh.

Farah, M.H.J. (1984) The neurological basis of mental imagery: A componential analysis. *Cognition,* 18: 245-272.

Green, D.W. and others. (1996) *Cognitive Science: An Introduction.* Blackwell Publishers, Oxford, UK.

Green, T.R.G. (1989). Cognitive dimensions of notations. In A. Sutcliffe & L. Macaulay (Eds.). *People and computers V,* (pp. 443-459), Cambridge: Cambridge University Press.

Green, T.R.G. (1990). The cognitive dimension of viscosity: a sticky problem for HCI. In: D. Diaper, D. Gilmore, G. Cockton & B. Shakel (Eds.) *Human-Computer Interaction - INTERACT'90.* (pp.79-86) North Holland: Elsevier Publishers, B.V.

Hegarty, M. (1992). Mental animation: inferring motion from static displays of mechanical systems. *Journal of Experimental Psychology: Language, Memory and Cognition,* 18(5), 1084-1102.

Hutchins, E. (1995). *Cognition in the wild.* Mass: MIT Press.

Johnson-Laird, P.N. (1988) *The Computer and the Mind.* CUP: Cambridge.

Kim, S. (1990) Interdisciplinary collaboration. In B. Laurel, B. (ed) *The Art of Human Computer Interface Design,* p31-45.

Kirsch, D. & Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science,* 18, 513-549.

Kuutti. K. & Bannon, L. (1993). Searching for unity among diversity: exploring the interface concept. In *Proceedings of INTERCHI'93,* (pp. 263-268). New York: ACM.

Larkin, J. H. (1989). Display-based problem solving. In D. Klahr & K. Kotovsky (Eds.) *Complex Information Processing: The impact of Herbert A. Simon.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Larkin, J. H. & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science,* 11, (1), 65-100.

Mantovani, G. (1996). Social context in HCI: a new framework for mental models, cooperation and communication. *Cognitive Science,* 20, 237-269.

Norman, D. (1980) Twelve issues for Cognitive Science. *Cognitive Science,* 4, 1-32

Norman, D. (1990) Four (more) issues for Cognitive Science. *Cognitive Science Technical Report, No. 9001,* Dept of Cognitive Science, UCSD, USA.

Norman, D. (1994). Cognition in the head and in the world, *Cognitive Science,* 17(1), 1-6.

Rogers (2000). Recent theoretical developments in HCI: their value for informing system design. (in prep).

Rogers, Y. & Scaife, M. (1997). How can interactive multimedia facilitate learning? In J. Lee (Ed) *Intelligence and Multimodality in Multimedia Interfaces: Research and Applications.* Menlo Park, CA: AAAI. Press.

Scaife, M. Curtis, E. and Hill, C. (1994) Interdisciplinary collaboration: a case study of software development

Sommerville. I., Rodden, T. Sawyer, P. Bentley, R. & Twidale, M. (1993). Integrating ethnography into the requirements engineering process'. In A. Finklestein, & S. Fickas (Eds.) *IEEE Symposium on Requirements Engineering* (pp. 165-173). New York: ACM.

Thagard, P. (1996) *Mind.* MIT Press: Cambridge, MA.

The Royal Society (1996). Interdisciplinarity - Transport and the Environment.
http://www.royalsoc.ac.uk/st_pol08.htm

Von Eckardt, B. (1993). *What is Cognitive Science?* MIT Press: Mass.

Vygotsky, L.S. (1978). *Mind in society: the development of higher psychological processes.* (M. Cole, V. John-Steiner, S. Scribner, E. Souberman, Trans.) Cambridge, MA: Harvard University Press.

Zhang, J. and Norman, D.A. (1994). Representations in distributed cognitive tasks. *Cognitive Science,* 18, 87-122.