

## The Careful Double Vision of Self

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### INTRODUCTION

This special issue honours John Self. John has always been at the creative and social centre of AIED. His contributions to the formation, evolution, and maintenance of the AIED discipline are legendary. He was secretary on the AIED Society management board from the Society's inception until last year and was also founding editor of the AIED Journal, serving as its editor-in-chief for over a decade. Through his efforts, the Society has become the leading advanced educational technology research society in the world and the Journal has become the flagship journal for the field, publishing high quality leading edge work, readily accessible through the web. In all of his administrative and editorial roles, John has demonstrated drive, integrity, depth, discipline, openness in decision making, care for individuals, and support for collegial interactions among AIED scientists.

Not coincidentally, John's research has also been infused with exactly these same qualities. John was the first to introduce the notion of a student model over a quarter century ago (Self 1974), and has been interested in student modelling (now more normally called learner modelling) ever since. Initially promoting the notion of the student model as a source of information for an intelligent tutoring system to adapt to individual learner differences, John, with graduate students and colleagues, has subsequently explored many aspects of student modelling, including formalizing student models (Self 1994), building student model shells (Paiva and Self 1995), being among the early researchers to explore opening the student model to the learner in order to promote reflection (Dimitrova, Self, and Brna 1999). He was also one of the first AIED researchers to investigate collaborative learning (Dillenbourg and Self 1995) and meta-cognition (Self 1995a). John was a pioneer in promoting rigorous models in AIED, proposing a new formal foundation for AIED he called computational mathematics (Self 1992, 1995b). John has written a number of highly influential issue-oriented papers, most notably his examination of ways around the (not so) "intractable" problem of student modelling (Self 1990b), his exploration of the many notions of openness (Self 1999a), and his promotion of "caring" systems (Self 1999b). John's work is not just theoretical: he validates it through applying his ideas in real world learning situations and believes strongly in the need to empirically test AIED systems with real learners. Through his own research (and his AIED Journal editorial policies) John has also been instrumental in keeping AIED interdisciplinary: AIED is the only field of learning technology that draws on and contributes to all of the following: (i) advanced computational techniques from computer science (especially artificial intelligence), (ii) deep knowledge of human cognition from psychology, (iii) deep understanding of social interaction from anthropology and sociology, and (iv) deep knowledge of teaching and learning from education. And serious and ground breaking as John's contributions are to the AIED field, he also knows the value of humour in helping along interesting discussions and new directions in the field. The field of AIED is truly Self-centred.

In the next two sections we explore two main threads of John Self's perspective: the need for AIED systems to be adaptive to each individual learner and the need to build solid foundations for the field. We then overview the papers in the special issue in the context of these two threads.

## **AIED CARES**

John Self (1999b) argues that AIED is the only field of advanced educational technology that is aimed at building "computer-based learning systems which attempt to adapt to the needs of learners and are therefore the only such systems which attempt to 'care' about learners in that sense." He further argues that AIED research "is the only part of the general IT and education field which has as its scientific goal to make computationally precise and explicit forms of educational, psychological and social knowledge which are often left implicit". In short, AIED *cares* and is *careful*.

AIED cares by trying to build systems that respond with subtlety and intelligence to the specific needs of each individual learner. Originally, AIED researchers were mostly interested in responsiveness to a learner's gaps in knowledge, but more recently have become interested in a much wider range of adaptivity to learner needs, including a learner's emotional needs, social situation, immediate context, goals, learning and cognitive style, etc. Such individualization can only be achieved by keeping a learner model that captures a wide range of learner characteristics for each learner. Thus, for example, we see research by (Del Soldato and du Boulay 1996) into affective modelling, (Moebus, Schroeder and Thole 1994) into modelling problem solving, and (Bull and McCalla to appear) into modelling cognitive style. The I-Help paper (this volume) models a variety of aspects of learners, including knowledge, sociability, and eagerness. Originally, AIED researchers mostly used such learner models to adapt the order of presentation of knowledge to be learned to meet individual differences. More recently, however, learner models have been used much more flexibly to adapt the look and feel of the interface, to find knowledgeable peer helpers, to support group interactions in virtual learning communities, to support knowledge negotiation, etc. One of the more interesting uses of the learner model is to make it scrutable (Kay 1999) to the learner, thus encouraging learner reflection. The STyLE-OLM system (this volume) further encourages such reflection by supporting learner interaction with their model as they learn.

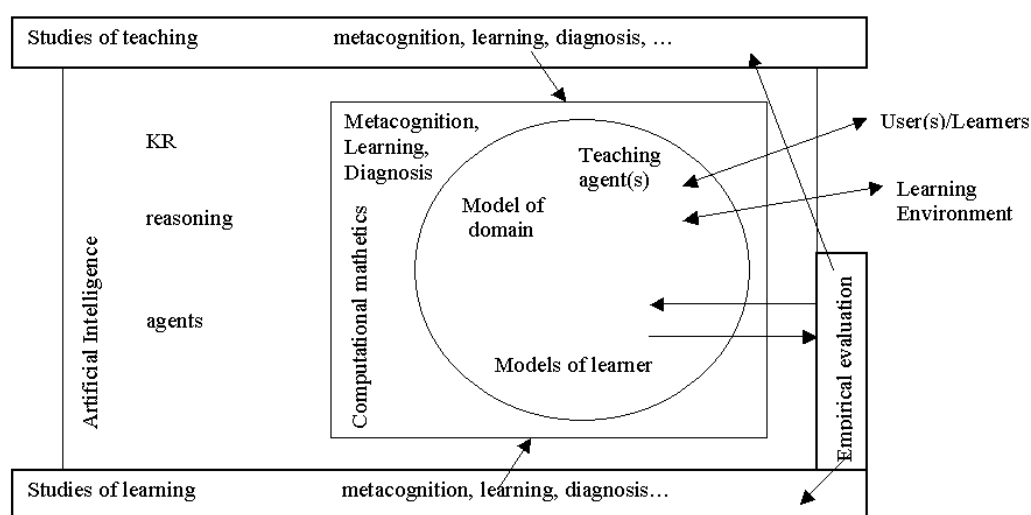
Other notions of responsiveness and caring are beginning to emerge in AIED research, based on interaction and collaboration (see MARCo, I-Help, and STyLE-OLM in this volume). In collaborative approaches, the entire social context of learning is taken into account (see Chan 1996, Dillenbourg and Self 1992). The role of the system in these approaches is often more nuanced than in the older tutoring system paradigm, intelligently supporting learning rather than replacing teaching. Such systems are caring in the sense that the system tries to keep the learner in control (or at least give the learner the illusion of control) and to support a wider variety of learning pedagogies. Even so, they usually incorporate a learner model in order to, in some way, personalize the interactions or the collaborations.

## **CAREFUL PATHS FORWARD**

As well as building caring systems, AIED is "careful" in the sense of requiring deep and well-justified examinations of human learning and the tools to support such learning. One aspect of this carefulness is carrying out empirical studies, to understand exactly what the learners are doing and how the system has impacted the learning. Some of these empirical studies are proof-of-concept; others are large-scale deployments, sometimes even with tens of thousands of learners (Koedinger, Anderson, Hadley, and Mark 1997). In fact, one of the most cited AIED journal papers has been a paper by Mark and Greer (1993) exploring AIED evaluation methodologies.

Another aspect of AIED's carefulness is a goal to build rigorous theoretical foundations for advanced learning technology. As usual, John Self is a pioneer in this effort (eg. Self 1990a). One of his major works (Self 1995b) provides a comprehensive long term perspective on building solid foundations for AIED. In this paper, Self notes: "The scientific study of learning, in so far as it exists today, is distributed around psychology, education, sociology and artificial intelligence. It does not form a coherent, integrated field of study and does not contribute reliably to the design of computer-based learning systems. While not wishing to suggest that such a discipline be created, we can daydream about how the design of AIED systems would be different if it were." Self then goes on to outline the parameters of a basic science of learning he calls computational mathetics, defined as "the study of matters pertaining to learning, and how it may be promoted, using the techniques, concepts and methodologies of computer science and artificial intelligence ... Computational mathetics would be, like computational linguistics, technically and theoretically based and oriented towards, but independent of, practical applications. In particular, it would be oriented towards the eventual design of computer-based systems to promote human learning."

Drawing heavily from John Self's computational mathetics ideas, we will now explore some of the important directions for caring and carefully built AIED systems. Figure 1 gives one, very simplified model of a careful vision of future AIED systems. It is based upon John's ideas of computational mathetics with its relationship, externally, to AI, teaching, learning, and, internally, to the general features of an AIED system.



**Figure 1** – Model of careful visions of AIED. Computational mathetics draws from a large theoretical base of Artificial Intelligence research and deep understanding of the effective learning and teaching. AIED systems, represented by the circle, are carefully evaluated, taking account of the environment. Since AIED systems embody theories of AI, teaching and learning, their careful evaluation provides validation for these theories.

Note the large base of AI forming the foundation for computational mathetics and AIED systems: AIED is a form of applied AI. Self clarifies his view of AI for building systems to support learning: "The key difference between AI and other forms of computer programming is that AI programs respond intelligently to situations not specifically anticipated by the programmer ...". Significantly, he continues: "AI would not be a coherent field of study if every application required the development of its own computational theory" (Self 1995b). AIED can similarly be made coherent through computational mathetics with its goal: "to provide the more formal analyses needed to complement present informal

argumentation and design. However, the level of formality is still low compared to other areas of theoretical AI, reflecting the difficulty of AIED and the little work so far done in this direction” (Self 1995b).

We can see this view reflected in the work of Self and his students, including the STyLE-OLM and MARCo papers in this special issue. Both are based upon AI techniques for knowledge representation and reasoning. Both extend and specialise those techniques to the needs of an AIED system. In a very different way, the I-Help system also relies on AI foundations: it contributes both to AIED and to research into agent architectures.

Within the computational mathematics box in Figure 1 are the parts of an AIED system. Any one system should be able to make use of parts of the computational mathematics foundations to implement the core functions of teaching, domain expertise, student modelling and other activities it needs to perform. All four of the papers in this issue are based on systems that have been implemented. They draw on differing amounts and types of computational mathematics and basic AI and they contribute to our better understanding of these foundations so that future systems will be more carefully caring for learners.

Above and below Figure 1's large AI block, we indicate the need to carefully develop our understanding of teaching and learning. From the earliest days of AI, there has been strong influence from those who study people. So too, for AIED. Again quoting Self (1995b): “AIED is interesting because of this constant interplay of ideas and it is important because of the potential contribution to the socially central aim of improving the quality of learning. Contributions to AIED come from many directions: primarily from computer science, psychology and educational research, but also from sociology, anthropology, philosophy and the many fields which are the topic of AI-ED systems.” It is when we embed these theories of teaching and learning into computational tools that we explore new elements of computational mathematics. Figure 1 also has a place for the learner, the learning environment, and the need to evaluate learners in that environment. This evaluation is important for judging the effectiveness of each new system. At the same time, if we view the building of AIED systems as an empirical science, with each new system being viewed as one more experiment, evaluation helps to inform our understanding of computational mathematics and the effectiveness of various models of domain knowledge, teaching, and learning.

Implicit in Figure 1 (and underlying the entire AIED enterprise) is the critical role of caring about the needs of the individual. This is a major source of the motivation for building on AI foundations. We need AI, and computational mathematics, to build systems that can cope with the complexity of supporting learning by people who differ on dimensions such as knowledge, learning preferences and needs, cognitive style not to mention different environments. Caring is computationally challenging!

## **THE PAPERS OF THE SPECIAL ISSUE**

The papers in this special issue illustrate various ways that systems can care for their learners and all four are examples of careful AIED research.

In the Bull et al paper, the keys to caring in the I-Help system are discussed. The I-Help system does not help learners directly, but depends on learners to help each other, either through public discussions or private one-on-one discussions between two learners. Learners interact with the I-Help system through the mediation of a personal agent that represents them in the system. Among other things, this personal agent can find them a “ready, willing, and able” helper through negotiations with the personal agents of other learners, or can find them relevant postings in the public discussion forums. To do this, a personal agent must keep or infer not only knowledge about its own learner, but also knowledge about other learners and knowledge about the nature of the postings in the public discussion forums. And, it isn't just domain knowledge that must be dealt with, but also knowledge of learners' goals, their cognitive and

social capabilities, and resource constraints and other contextual elements. Rather than keeping large stored models, the modelling is a “just in time” computation, carried out in context as needed to meet specific goals. The knowledge informing these computations is garnered from many “fragmented” sources: learners inform their own personal agents about their capabilities and goals as well as the capabilities and social abilities of other learners with whom they have interacted; agents observe the behaviour of learners; agents “gossip” with one another about learners. The I-Help system has been deployed in a long-running real-world study, and has proven to be useful and appreciated by the learners. It is, however, still a research project stimulating the exploration of many AIED issues, especially issues involved in making AIED systems more caring in Self’s sense of this.

I-Help has a number of features that increases its ability to care for its learners. The range of characteristics it can access about a learner is considerably broader than in most other systems, allowing a broader interpretation of the learner’s needs. Moreover, by actively computing a model as needed it can be highly sensitive to the immediate goals of the learner and react to constraints such as time pressure. Perhaps most importantly, I-Help works to leverage learners helping each other, rather than being solely responsible for helping the learner itself: it tries to create, stimulate, and maintain a social context in which learners care for each other. In I-Help, caring is reciprocal in two senses: a learner cares for another learner by helping them and in return may get help in the future; and a learner cares for their personal agent, keeping it informed about some of their own goals and their own and other learners’ personal characteristics and in return the agent finds them an appropriate helper or an appropriate forum. In terms of Figure 1, I-Help tries to tightly bind learning and teaching, with minimal (but multiple) models of learners and teachers supporting the interaction. The I-Help system depends heavily on learners trusting the system, in particular trusting their personal agent. No caring would happen without this. Trust is maintained through care in the sharing of information and through allowing learners to maintain public anonymity through aliases. There is a lurking paradox here, however. The ability of I-Help to react with subtlety and nuance to a learner’s needs, i.e. to care for that learner, may depend on agents sharing information about learners; but that very sharing may lead to learner distrust of the system, thus diminishing the learner’s desire to reciprocally care for the system and for other learners. The I-Help system not only is caring, but is also careful in that various versions have been tested in real world deployments, some with many hundreds of learners.

In a very detailed paper Dimitrova describes the STyLE-OLM system. It engages learners in an interactive dialogue about their knowledge, represented in a learner model. As in the typical AIED system in Figure 1, STyLE-OLM is deeply embedded in AI. The system draws on a wide variety of AI techniques to support its interactions with the learner: conceptual graphs to represent the learner’s domain knowledge; belief revision techniques to maintain the learner model; and a variety of natural language dialogue techniques, most importantly the use of speech acts to help interpret and generate utterances and the use of several dialogue games to direct the interaction between the learner and the system. This has allowed a proof-of-concept STyLE-OLM prototype to be effective in helping learners gain mastery over new terminology in a financial domain.

STyLE-OLM is an experiment in interactive open learner modelling. While most open modelling research aims to display all or part of a learner model to the learner in order to stimulate the learner to reflect upon his or her knowledge, Dimitrova (following up on Self’s (1990b) observations on the power of interactive diagnosis and Bull’s (1997) work on collaborative learner modelling) emphasizes the importance of going beyond just displaying the model. STyLE-OLM creates interaction between the learner and the system about the model being kept by the system. Such interaction not only improves the system’s ability to understand the learner (interactive diagnosis) but also better stimulates reflection than merely displaying the model, a claim further supported by other negotiated learning approaches (Elsom-Cook and Moyse 1992). As in I-Help, learner modelling is a reciprocal responsibility of both the learner and the system. The learner helps the system to get a more accurate and deeper understanding of

himself/herself, and in return gets a better understanding of the domain. This allows both to care for each other better.

A very similar spirit is reflected in the paper describing MArCo. This is undoubtedly due to the fact that both of these papers report research of John Self's recent PhD students. In addition to both having mixed-case system names (©), both explore ways to build personalised teaching systems from strong AI foundations. These systems can be seen as experiments into the elements for computational mathematics. They serve as a foundation for improving our understanding of how we can rigorously, carefully, go about building better systems to support learning.

The MArCo work begins with a detailed review of the literature on supporting group decision processes and the challenges of managing conflict and change. So MArCo supports learning about the social skill of working in a group. This work explores ways to help learners improve their participation in group problem-solving processes. It especially focuses on the exploiting group conflicts to facilitate reflection and subsequent articulation of concerns as a driver for change. This builds upon Self's earlier Dormobile framework (Self 1995a) and represents a refinement of the formalism. It introduces a computational model that has the usual beliefs, goals and intentions and also has additional operators needed to model the cognitive state of agents engaging in group planning. The paper teases out and refines the notion of conflict to distinguish those situations where a system should intervene in the group interaction.

The computational model has been implemented as part of system that enables groups of users to construct PERT charts as part of the planning of a group activity. MArCo plays the role of mediator, with the goal of helping deal with conflict by prompting the group members to stop and reflect about the problems and then to articulate them. The paper reports evaluation of this system and careful analysis of the utterances of users working as a group to construct a PERT chart. It indicates that interaction by a mediator, according to the model of conflict, did increase the participants' reflection about the cause of conflict and articulation of it to other group members. This, in turn, helps the participants to operate more effectively as members of group, taking care to appreciate the different understanding of others in the group.

The paper by Katz and Allbritton presents a careful exploration and assessment of the common belief that learning is enhanced if there is a discussion after learners have tackled a problem-solving task. Like the STyLE-OLM and MArCo papers, we see considerable focus on the importance of reflection in learning. The paper reports a thorough study of approximately 150 learner-tutor dialogues observed after learners had finished working on physics problems. These were coded according to who (learner or tutor), initiated the dialogue. They were also analysed in terms of tutoring styles of the learners as well as differences in student ability. Katz and Allbritton also compared the character of dialogue between teacher and learner during the problem-solving phase and afterwards, in the review of the task. Among the highlights of this analysis are that the tutors did apply different strategies for different learners and that, at the same time, there were some interesting categories of tutor, described as "opportunists", "stashers", and "parcelers". The study also indicated a focus on teaching the underlying conceptual knowledge within this context. From this foundation, Katz and Allbritton specified rules capturing the pedagogic planning they had observed in the human tutors. This is the codification of a careful study of teaching in a carefully formulated computational model, one of critical directions for careful AIED, indicated in Figure 1.

While this first study provided considerable insight into the behaviour of tutors and learners, it did not assess the *effectiveness* of different approaches. This empirical evaluation of learning effectiveness is central to a careful path forward for AIED. This was addressed was a second study. It indicated that learners who were encouraged to reflect learned more. Moreover, canned feedback appeared to have been as effective as human tutor feedback. As a whole, this paper both contributes to our theoretical understanding of the relationship between teaching and learning and also explores how this might be

embodied in a teaching system. Thus, the theoretical side of AIED and the applied side progress hand-in-hand, as suggested by computational mathematics.

## CONCLUSION

The four papers in this special issue are appropriate tributes to John Self's double vision of AIED as a caring and careful field. We expect that, in the coming years, work exploring this double vision will be doubled and re-doubled as AIED begins to fulfill its potential to provide the deep foundations a science of learning and teaching has always needed.

## Acknowledgements

Gord McCalla would like to acknowledge the financial support he has received for his AIED research from Canada's Natural Sciences and Engineering Research Council and from the TeleLearning Network of Centres of Excellence. Judy Kay thanks the Smart Internet Technology Cooperative Research Centre, for supporting work towards caring personalised systems, carefully founded and evaluated.

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