36

Catalyzing Collaborative Learning and Collective Action for Positive Social Change through Systems Science Education

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[A system is] any portion of the material universe which we choose to separate in thought from the rest of the universe for the purpose of considering and discussing the various changes which may occur within it under various conditions.

Willard J. Gibbs

The community stagnates without the impulse of the individual. The impulse dies away without the sympathy of the community.

William James

Introduction

Resolving complex scientific and social problems is often impeded by three interdependent human limitations: poor critical thinking skills; no clear methodology to facilitate group coherence, consensus design, and collective action; and limited computational capacities. Third level science education is designed to facilitate the development of generic critical thinking skills, but often does so with only limited success (Kuhn, 2005). Furthermore, third level science education generally focuses on domain-specific computational skills that do not necessarily transfer well outside of the domain in which they are normally used, and training in the use of systems science methodologies that facilitate group coherence, consensus design, and collective action is rarely observed (Warfield, 1974, 2006). We believe that these problems can be addressed by integrating within a systems science curriculum three thought structuring technologies: Interactive Management (IM) for system design, Argument Mapping (AM) for critical thinking, and Structural Equation and System Dynamics Modeling for mathematical modeling. Such a curriculum would promote systems thinking and cooperative enquiry skills in relation to basic and applied science problems, while also facilitating collective action in the context of a multidisciplinary action research agenda.

Embedding Systems Science in the School and University Curriculum

John Warfield (1925 – 2009), past president of the International Society for the Systems Sciences, devoted most of his career to the task of building a viable systems science. In his view, systems science is best seen as a science that consists of five nested sub-sciences, which can be presented most compactly using the notation of set theory (Warfield, 2006). Let **A** represent a science of description. Let **B** represent a science of design. Let **C** represent a science of complexity. Let **D** represent a science of action (praxiology). Let **E** represent systems science. Then

$$\mathbf{A} \subset \mathbf{B} \subset \mathbf{C} \subset \mathbf{D} \subset \mathbf{E} \qquad \mathbf{(1)}$$

This suggests that we can learn something of systems science by first learning a science of description (e.g., physics, chemistry, biology, psychology, sociology, economics). Then we can learn a science of design that includes a science of description. The science of design is fundamental if our goal is to redesign systems (e.g., the intelligent redesign of school systems via effective knowledge import from biology, psychology, sociology and economics). The science of design implies the use of tools that facilitate the building of structural hypotheses in relation to any given problematic situation, a problematic situation that may call upon the import of knowledge from any given field of scientific inquiry. Next we can learn a science of complexity that includes a science of description and a science of design. The science of complexity is fundamental if our goal is to integrate a large body of knowledge and multiple disparate functional relations that different stakeholders believe to be relevant to the problematic situation. Next we can learn a science of action that includes a science of description, a science of design, and a science of complexity. The science of action is fundamental if our goal is to catalyze collective action for the purpose of bringing about system changes that are grounded in the sciences of description, design, and complexity. Broadly speaking, if students are to learn a form of systems science that can be used to promote successful collective action in science and society, they need to learn how the domain-based science of description that is their primary focus of enquiry at University can be integrated in principle with other domains of enquiry in the context of a broader science of design, complexity, and action.

Warfield's vision for applied systems science is instantiated in part in the systems science methodology he developed, Interactive Management (IM). IM is a software-assisted thought and action mapping process that helps groups to develop outcomes that integrate contributions from individuals with diverse views, backgrounds, and perspectives. Central to IM is a matrix structuring process that facilitates groups in developing structural hypotheses that map systems of interdependencies, based on the consensus-based logic of the group (see below). Although the mathematical algorithms that underpin Warfield's IM software are relatively complex -- drawing in particular upon the mathematics of matrices -- the application of the software for the purpose of generating a structural hypothesis in relation to any given problematic situation is reasonably straightforward. In fact, the rationale for separating the computational complexity of structuring from the process of dialogue, information search, deliberation, and voting in a group was very explicit in Warfield's view. The IM software is designed to alleviate the group of computational burden and thus allow them the opportunity to maximize the processes of creative idea generation, dialogue (see Wegerif, this volume), information search, critical thinking and voting in relation to key binary relations in the overall problem structure.

Consistent with Warfield's view, we believe that tool-mediated learning processes can be instrumental in promoting the development of key individual talents and successful team dynamics. The design of learning tools is critical in this context. Warfield argued that the tools of systems science will be most effective if they integrate our capacity to share meaning using words, represent causality using graphics, and model complexity using mathematics (see Figure 1). IM integrates all three of these components in its design. Warfield also highlights the distinction between the mathematics of content and the mathematics of structure. IM draws upon the mathematics of structure to convert matrix voting structures of users into a graphical representation of the relations they have mapped in their problematique. However, in the context of mapping problem structures or enhancement structures (i.e., problem resolution structures) that import knowledge from domain-based sciences, it is feasible and perhaps desirable for the purpose of model fit evaluation to estimate effect sizes for discrete functional relation in a matrix structure and thus test the empirical validity of models. This can be done by testing structural models or dynamic models that are analogues or extensions of the models generated by a group in an IM session. Notably, a recent study by Chang (2010) compared the results of IM with Structural Equation Modeling (SEM) and found a high degree of consistency between models generated by participants in an IM session and quantitative relationships confirmed in SEM. Although detailed mathematical specification is beyond the scope of this chapter, consistent with Maani and Cavana (2000), we believe that IM modelling can be used as a foundational step for groups that seek to develop consensus-based computational models in a team setting.

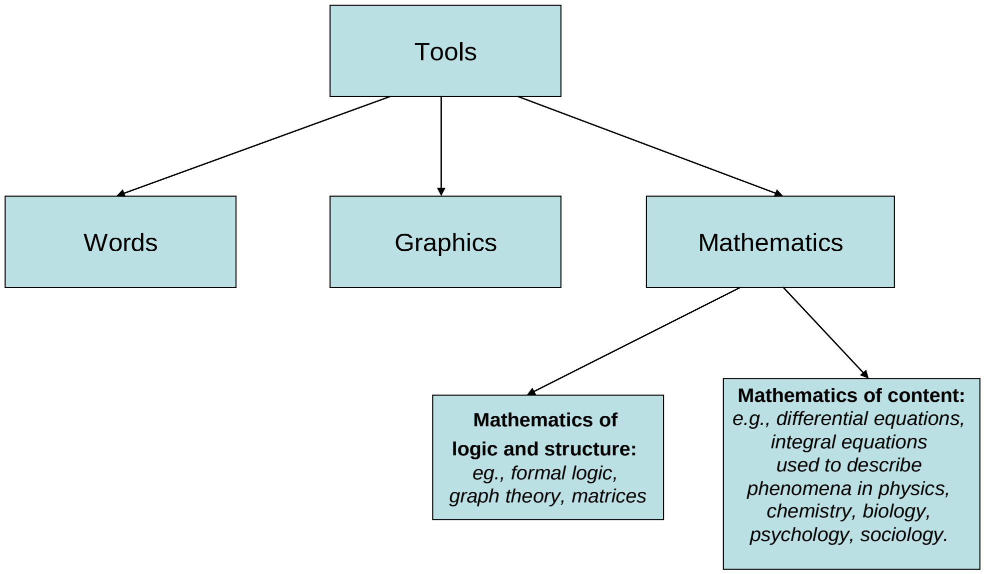

Figure 1. Systems science tools needs to work with our capacity to share meaning using words, represent causality using graphics, and model complexity using mathematics.

Methods for integrating systems science tools into the curriculum are still poorly developed. For example, less well developed in Warfield's thinking are: (a) strategies for importing the facts and relations of disparate descriptive sciences into group design efforts, (b) strategies for quantifying problematique model fit by weighting and measuring discrete relations in matrix structures and computing statistical fit indices and further integrating with system dynamics modeling tools (Maani & Cavana, 2000); (c) teaching the critical thinking skills necessary for the analysis and evaluation of scientific evidence embedded in problematiques, and (d) cultivating domain-specific systems level thinking in students at school level prior to their entering university (Stein, Dawson & Fischer, 2010). In order to advance Warfield's vision of systems science education and further develop applied systems science, we are developing a tool and a teaching framework that integrates critical thinking and systems modelling in a broader pedagogical framework. Below we outline a framework for systems science education that involves the development of tools, talents, and teams. We then describe the IM approach in more detail and how we have integrated our newly developed IM tool with an argument mapping tool in an effort to facilitate individual talents and enhance team functioning.

Tools, Teams and Talents

Central to our framework is the development of tools, talents, and teams (see Figure 2).

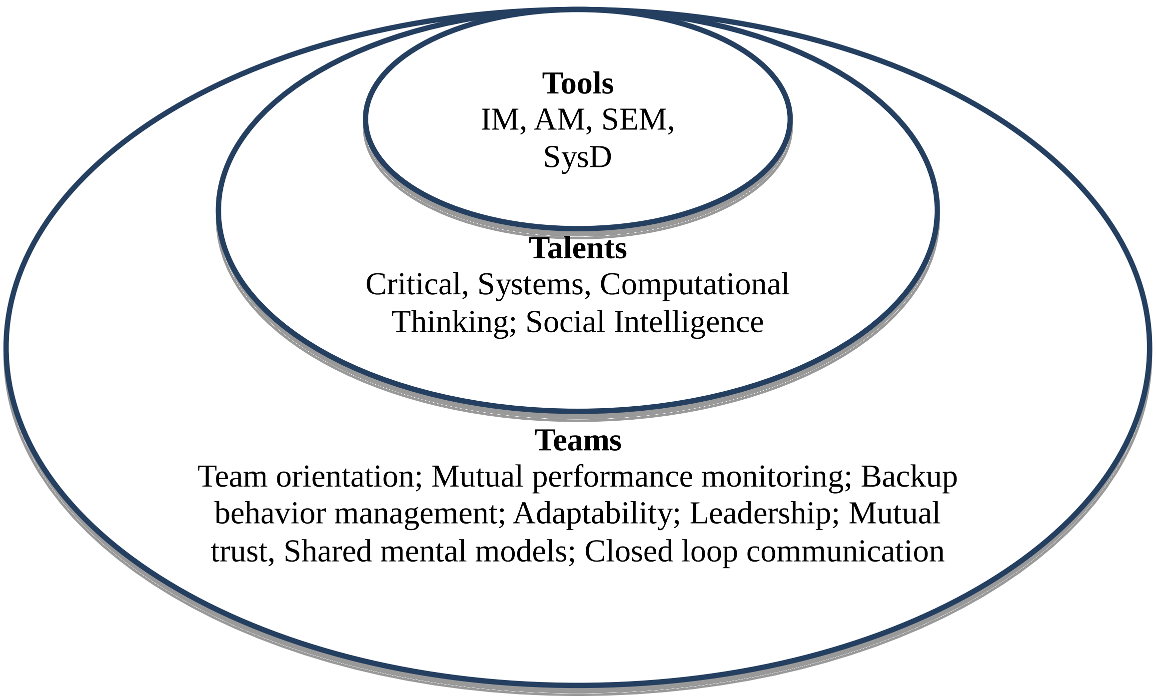

Figure 2. Three levels in a framework for systems science education -- Tools, Talents and Teams.

Note: IM = Interactive Management, AM = Argument Mapping, SEM = Structural Equation Modelling, SysD = System Dynamics.

We believe that developments across these three levels are reciprocally reinforcing, in the sense that good tool design should facilitate the development of key individual talents while also promoting effective team dynamics , much like efforts to promote effective team dynamics should accelerate the development of individual talents and the development of tool use skills . We also believe that systems science education should not be limited to the classroom – talents and teams develop in a more contextualized manner when systems science education extends to cooperative action in the context of real-world social problems, whereby students are given the opportunity to work with community stakeholders on real world problems. In our teaching framework, teams use their talents and tools to work on specific *tasks* focused on the resolution of problems within specific *territories*. The notion of *tasks* is consistent with Warfield's vision for applied systems science, which is rooted in the philosophical school of pragmatism (Warfield, 2006) and is applied and task-oriented in its focus. The notion of *territories* is used to reinforce the idea that human problems function within an ecosystem, or territory of influence, and thus the resolution of these problems involves human action within a specific territory. Problem description and modelling only serves the purpose to facilitate understanding and perspective in relation to concrete adaptive action within a territory of influence (Vennix, 1996). However, as noted above, IM modelling can be used as a foundational step for groups that seek to develop consensus-based computational models in a facilitated team setting using either structural equation modelling tools such as Amos[1] or Mplus[2], or System Dynamics tools such as Vensim[3] or Powersim[4].

Consistent with Warfield's vision and the majority of previous applications of IM, our teaching framework focuses squarely on efforts to resolve complex social problems and our tool-mediated teaching processes are designed to counteract the three human limitations noted above that often impede the resolution of complex social problems: poor critical thinking skills, no clear methodology to facilitate group coherence, consensus design and collective action, and limited computational capacities. Below we describe the IM process in more detail, how it advances upon other group decision support systems, and how we have integrated IM with AM in our teaching method.

Developing Teams and Talents using Interactive Management and Argument Mapping

Over the past three decades, the use of computer-based group decision support systems has become increasingly prevalent. Such systems are designed to increase efficiency in the context of group decision making and problem solving. Notably, a variety of decision support tools, such as Group Explorer and Decision Explorer have been used to help stakeholders to develop management strategies. Group Explorer, for example, facilitates the rapid declaration by group members of problems which they feel are negatively impacting on their goals. The tool also allows groups to map these problems in causal maps, and work together to agree upon priority goals (Ackermann et al, 2005; Eden & Ackermann, 2001; Williams et al, 1995). The use of tool allows the rapid generation of ideas because group members work in parallel, not sequentially; ideas are generated anonymously , which allows for greater participation from inhibited group members, and the expression of ideas which may be unpopular (Kraemer & King, 1988; Nunamker et al., 1988). Furthermore, the complex graphical representations of problem issues are immediately available to the group (Ackermann et al, 2010).

Despite the success and utility of many such decision support systems, they are not without limitations. For example, resolving complex problems often demands that groups move beyond the anonymity of ideas. It is vital that ideas can be clarified and integrated in a manner that enhances group understanding (Broome & Chen, 1992). Furthermore, one potential issue arising from computer-assisted problem solving is information overload. In a decision support system whereby simultaneous entry of ideas by all participants in possible, the set of ideas can quickly become overwhelming for group members, and thereby has a negative effect on problem solving and decision making processes. Warfield (1990) highlights "The Law of Requisite Parsimony", which states that there is a need to control the rate at which information is presented for processing in order for avoid overload during the design process. In order for group decision support systems to optimize their potential, and the potential of the group, it is necessary that they be designed in light of the limitations of human cognition.

[1] http://www.spss.com.hk/amos/
[2] http://www.statmodel.com/
[3] http://vensim.com/
[4] http://www.powersim.com/

IM was developed specifically to overcome many of the limitations described above. Established as a formal system of design in 1980 after a developmental phase that started in 1974, IM was designed to assist groups in dealing with complex issues. The theoretical constructs that inform IM, developed over the course of more than 2 decades of practice, draw from both behavioral and cognitive sciences, with a strong basis in general systems thinking (see Ackoff, 1981; Argyris, 1982; Cleveland, 1973; Deal & Kennedy, 1982; Kemeny, 1980; Rittel & Webber, 1974; Simon, 1960). Emphasis is given to balancing behavioral and technical demands of group work (Broome & Keever, 1989) while honoring design laws concerning variety, parsimony, and saliency (Ashby, 1958; Boulding, 1966; Miller, 1956).

IM has been applied in a variety of situations, including assisting city councils in making budget cuts (Coke & Moore, 1981), developing instructional units (Sato, 1979), designing a national agenda for pediatric nursing (Feeg, 1988), creating computer-based information systems for organizations (Keever, 1989), improving the U.S. Department of Defense's acquisition process (Alberts, 1992), defining global challenges (Christakis, 1987), improving Tribal governance process in Native American communities (Broome, 1995), managing cultural issues in the automotive industry (Staley & Broome, 1993); and promoting peacebuilding in divided societies (Broome, 2006). Participant testimonials at the end of workshops, together with changes in organizational and institutional policies that resulted from IM sessions, provide evidence for the individual learning and system change that is possible through the IM process.

Typically, IM sessions progress through a series of steps. First, a group of key stakeholders, usually ranging in size from 8-15 but with the possibility of involving much larger groups,with an interest in resolving a problematic situation come together in a situation room and are asked to generate a set of 'raw' ideas (commonly 50 – 200) about what might potentially have a bearing on the problem they all agree exists. Group discussion and multi-voting procedures help the group to clarify the sub-set of ideas that bear upon the most critical problem issues. Next, using IM software, each of the critical issues are compared systematically in pairs and the same question is asked of each in turn: "Does A influence B?". Unless there is majority agreement that one issue impacts upon another, the relation does not appear in the final analysis. After all the critical issues have been compared in this way, IM software generates a problem structure (or problematique) showing how the issues are interrelated. The problematique can be displayed for discussion by the group. The problematique becomes the launch pad for planning solutions to problems within the problem field. The logical structure of problems is visible in the problematique and when generating solutions, action plans are aimed at resolving problems in a logical and orderly manner. When the group is happy that they have modeled both the problem field and the best possible set of solutions, the IM session closes and the group leaves with a detailed action plan, a specific set of goals to work on, and the roadmap and logic describing how all the various plans and goals of each member will work together to resolve the original problem. Notably, the IM methodology can be used to structure problems, objectives, options, competencies, and so on, using a variety of different relational statements (e.g., aggravates, enhances, promotes, supports, etc.).

More detailed descriptions of IM sessions are provided in Warfield and Cardenas (1994) and Warfield (2006). We have also made use of the IM methodology in a conference setting involving upward of 100 participants, specifically, to structure barriers to wellbeing in Ireland (Hogan & Broome, 2012) and objectives designed to enhance the wellbeing of the people of Ireland (Hogan & Broome, 2013).

By way of example of an application of IM within an educational context, presented below is the outcome of a session conducted in a *Thinking, Modelling and Writing in Psychology* module in NUI Galway, in response to the trigger question, *What are the most important skills and dispositions of good critical thinkers?*. Table 1 illustrates the top ranked skills and dispositions of good critical thinkers, as voted upon by the students. Students then used the IM software to structure the interdependencies among the highest ranked skills and dispositions (Figure 3).The problematique is to be read from left to right, with paths in the model interpreted as 'significantly enhances'.

Table 1. Top Ranked skills and dispositions for CT

Top Five Skills	Top Five Dispositions
1. The ability to clearly say what it is you want to say	1. The willingness to detach from one's own beliefs
2. The ability to evaluate the strengths and weaknesses of an argument	2. The willingness to recognise limited knowledge or uncertainty (e.g. we may not have enough knowledge of a topic to confidently think critically about it)
3. The ability to converse and engage with others to expound personal views and experiences	3. The willingness to systematically write an essay in order to achieve a goal
4. The ability to logically say what you want to say in a concise manner	4. The willingness to question one's own assumptions and thinking
5. The ability to draw a conclusion about a topic based on its context and what we know about the topic already	5. The willingness to listen properly

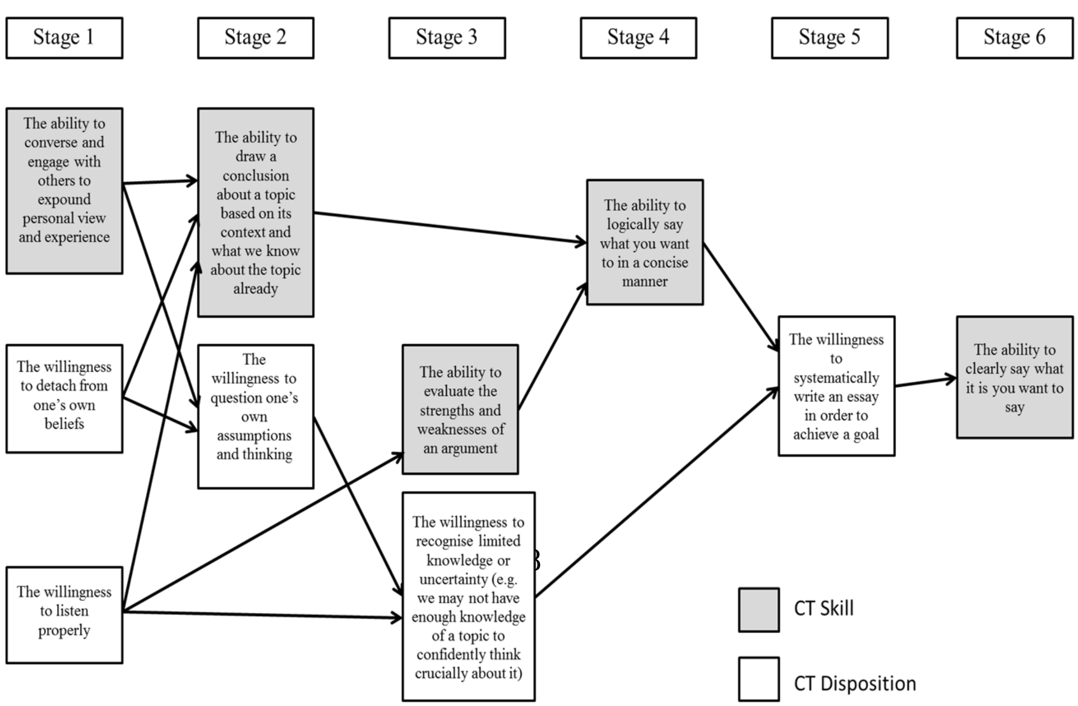

Figure 3: Sample Enhancement Structure of Skills and Dispositions Required for Critical Thinking. (Designed by *Thinking, Modelling and Writing* students as part of an introduction to CT and IM. Paths in the model are to be interpreted as 'significantly enhances')

We have recently integrated our IM software with argument mapping (AM) software. Although Warfield recognized that the critical thinking skills of participants in an IM session are often limited, he rarely discussed the particulars of these skills and how they might be developed in parallel with training in the use of IM. In the context of resolving problems that call upon the knowledge of diverse stakeholders, it is important to recognize that informed judgments in relation to key system relations imply the ability to think critically and reflectively in relation to one's own knowledge and the knowledge presented by others (Facione, 1990; Kuhn, 2005)

As defined in *The Delphi Report* (Facione, 1990), critical thinking involves:

"…purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based." (p. 3)

While a variety of training techniques can be used to enhance critical thinking skills, a recent meta-analysis by Alvarez-Ortiz (2007) suggests that the explicit use of argument mapping training is one of the most effective methods of training critical thinking skills. Furthermore, with research studies demonstrating the largest gains in knowledge growth and critical thinking skills deriving from cooperative enquiry (Johnson & Johnson, 2009), and with computer supported argument mapping tools now widely available and widely applied in third level education (van Gelder, Bissett, & Cumming, 2004), it is not difficult to see how the development of critical thinking skills through cooperative enquiry using argument mapping tools can fit within Warfield's vision for systems science education. Specifically, if one considers each of the binary relations in a larger structural hypothesis (or problematique) to represent a specific claim, then it is easy to see how a structural analysis and evaluation of the evidence used to support this claim can be unpacked through an argument map. Furthermore, with easy access to the Web of Science and other search engines, it is possible for students working together to analyse and evaluate a particular claim in a structure, specifically, by sourcing available knowledge and considering the credibility, relevance, and logical significance of this knowledge to the relation under investigation. For example, students who participate in an IM session may agree after open deliberation that (a) the ability to question one's own assumptions and thinking *significantly enhances* (b) one's capacity to evaluate the strength and weaknesses of an argument. This claim can be evaluated on deeper level in the context of an unfolded argument map, specifically, by sourcing available knowledge and considering the credibility, relevance, and logical significance of this knowledge to the relation under investigation (see Figure 4).

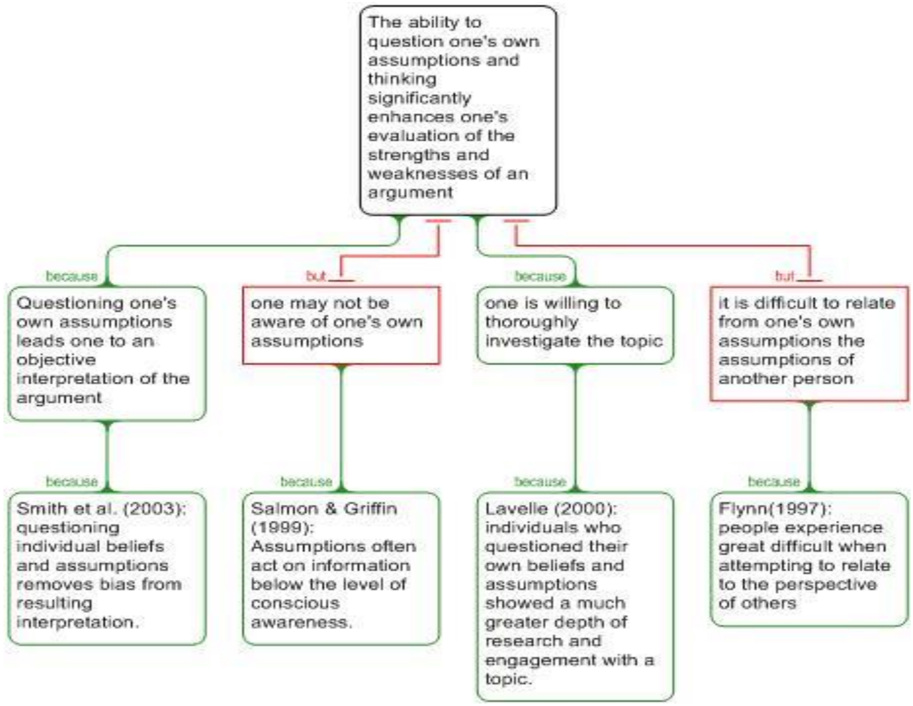

Figure 4: Argument Map Exploring How the Ability to Question One's Assumptions and Thinking Enhances Evaluation Skills.

As it is currently used, IM is a deeply engaging and cooperative process. However, when it is further merged with cooperative argument mapping (AM) work, the cooperative enquiry process is transformed into a process that explicitly links the science of design with the sciences of description in Warfield's scheme. More specifically, students who are mapping out a problematic situation are called upon to source and evaluate scientific evidence to support their beliefs as to the nature of discrete paths of influence in a problematique. Also, for problematic situations that draw upon multiple sciences of description, it is evident that students working in multidisciplinary teams will be exposed to arguments from multiple scientific domains and will have to learn to analyse and evaluate these arguments in cooperation with others. While it might be assumed that only those with specialized knowledge of domain-specific science content will be able to analyse domain-specific arguments and evidence, we believe that the knowledge and perspectives of students from multiple scientific backgrounds will help to enhance the creativity and the overall quality of evaluation and inference work. This can be accomplished through a generic systems science module that is run in parallel with all other domain-specific science education programmes at university, with classes consisting of small groups of 12 – 20 students from multiple disciplinary backgrounds working together on common problems. Within this framework it is possible to cultivate key talents of *critical thinking*, *systems thinking* and *computational modelling skills.*

Notably, as is the case with Decision Support Systems such as soft systems methodology (Checkland, 1989) strategic choice (Friend, 2001) and strategic options development and analysis (Eden & Ackerman, 2001) , effective tool design needs to be coupled with effective instructional design and effective management of teams in order for individual talents to be cultivated and coordinated in a group project setting (Eden & Ackermann, 2006). While the learning sciences have provided a great deal of insight into the cultivation of key talents at the individual level, including the cultivation of CT skills using argument mapping training programmes (Dwyer, Hogan, & Stewart, 2013), more work is needed to understand the optimal conditions needed to coordinate talents in a group project setting. Systems science education as Warfield envisioned it requires a perspective on the nature of effective teams and how to sustain effective team performance.

Based on the work of Salas, Sims and Burke (2005), we highlight eight aspects of effective teams that need to be cultivated as part of a systems science education programme. Salas, Sims and Burke (2005) suggest that a (1) team orientation, (2) mutual performance monitoring, and (3) backup behavior management are key competencies of effective team members. Effective teams also display (4) adaptability or flexibility and (5) effective team leadership (see Table 2). These 'Big 5' of effective teams are supported in turn by three coordinating mechanisms: (a) mutual trust, (b) shared mental models, and (c) closed loop communication.

Table 2. Eight aspects of effective teams that need to be cultivated as part of systems science education

Team Orientation – a preference for working with others and also a tendency to enhance individual performance through the coordination, evaluation, and utilization of task inputs from other members.
Mutual Performance Monitoring – team members maintain an awareness of team functioning by monitoring fellow members work in an effort to catch slips/mistakes
Backup Behaviour Management – anticipate other team members needs through accurate knowledge about their responsibilities. Includes ability to shift workload among members to achieve balance during periods of high workload or pressure
Adaptability – adjust strategies based on information gathered from the environment and through the use of backup behaviour and reallocation of intra-team resources.
Team Leadership – ability to direct and coordinate team activities, assess performance, assign tasks, develop team knowledge, skills, and abilities, motivate team members, plan and organize, and establish a positive atmosphere
Supporting Coordinating Mechanisms
Mutual Trust – The shared belief that team members will perform their roles and protect the interests of their teammates.
Shared Mental Models – An organizing knowledge structure of relationships among task components the team in engaged in and how the team members will interact
Closed-loop communication – The exchange of information between a sender and a receiver irrespective of the medium. Involves (a) the sender initiating a message, (b) the receiver receiving the message, interpreting it, and acknowledging its receipt, and (c) the sender following up to insure the intended message was received

Both process and outcomes analyses suggest that the IM methodology facilitates effective team dynamics in the context of appropriate feedback and facilitation (Harney, Hogan and Broome, 2012, 2014). For example, Harney, Hogan & Broome (2012) investigated the effect of open versus closed IM voting and dispositional trust on perceived consensus, objective consensus and perceived efficacy of IM technology. Two groups of 15 undergraduate students came together to structure the interdependencies between positive and negative aspects of social media. Participants high and low on dispositional trust were identified and were randomly assigned to either an open or closed voting condition. Those in the closed voting group were not permitted to discuss the problem relations, but consensus votes were recorded by the group design facilitator. This scenario simulated an online voting system where participants converged upon a decision without direct contact or open dialogue in advance of voting. The open group were allowed to discuss the relations before voting. Notably, the results of this study indicated that participants with higher dispositional trust, and those in more open working groups, reported higher levels of perceived consensus and higher levels of perceived efficacy of the IM technology.

These results, combined with results from studies showing increased learning gains in more open and interactive groups (e.g. Ada, 2009) suggest that open discussion and dialogue are critical factors in the success of collaboration using tools such as IM. Harney, Hogan & Broome (2014) investigated the effects of generic versus metacognitive feedback on levels of perceived and objective consensus and argumentation style of participants high and low in dispositional trust, in the context of an Interactive Management (IM) session. Four groups of undergraduate psychology students (*N* = 75) came together to discuss the negative consequences of online social media usage. After screening for trust scores, participants high and low on dispositional trust were randomly assigned to either a generic or metacognitive feedback condition. In each feedback condition, an independent facilitator was given a specific set of prompts or instructions which could be used as part of the feedback process. The generic feedback condition used generic prompts to maintain discussion during idea generation and idea structuring phases of IM, for example, "Does anyone else have an opinion on this idea?". The facilitator in the metacognitive feedback group also provided process-level and self-regulatory feedback prompts that aimed to promote deeper analysis and evaluation of ideas and problem relations, for example, "Is there any evidence to support your claim?"
Levels of perceived consensus, objective consensus, and perceived efficacy of the collaborative learning methodology were measured before and after the IM session. Results indicated that those in the metacognitive feedback condition, and those with higher levels of dispositional trust, reported higher levels of perceived consensus in response to the group design problem. Furthermore, those in the metacogntive feedback condition also reported significantly higher levels of perceived efficacy of the ISM process compared to those in the generic feedback condition. Finally, analysis of the dialogue from the IM sessions revealed that those in the information feedback condition exhibited higher levels of sophistication in their arguments, as revealed by the Conversational Argument Coding Scheme (CACS) (Seibold & Meyer, 2007).

Related research suggests that computer-supported collaborative learning (CSCL) can facilitate creative, efficient and effective problem solving that promotes both intellectual development and social interaction (Stahl, Koschmann & Suthers, 2006; Engelmann and Hesse (2010); see also Pinkart, this volume). As noted by Salas, Sims and Burke (2005), one important lesson that can be derived from existing research is that effective teams require more than just task work (e.g., interactions with tasks, tools, machines, and systems). Teams do more than simply interact with tools; they require the ability to coordinate and cooperatively interact with each other to facilitate task objectives though a shared understanding of the team's resources (e.g., members' knowledge, skills, and experiences), the team's goals and objectives, and the constraints under which the team works. Essentially, teams also require teamwork, and we believe that the application of systems science tools embedded in a systems science curriculum can be used not only to cultivate cognitive talents such as critical and systems thinking and computational modelling skills, teamwork can be used to enhance social intelligence and effective team dynamics.

A logical approach to systems science education

Implementing systems science education may not be a simple endeavor, but if we follow the suggestions of Warfield, it is relatively straightforward: we can learn something of systems science by first learning a science of description (e.g., physics, chemistry, biology, psychology, sociology, economics). Students arriving to university to study science will have a foundational understanding of science that will develop over time in the right conditions. We can further enhance this understanding by offering students a parallel systems science training programme. For example, in the context of a three or four year science education program, students can first learn argument mapping and critical thinking skills that reinforce and deepen their understanding in relation to the facts and relations of any given domain-based science. Furthermore, the largest effect sizes in terms of growth in critical thinking ability will be achieved if there is a cooperative enquiry component to the teaching of science and related argumentation skills. Therefore, we suggest that during the first year of any science education programme, students enrolled in the systems science education programme will take a generic argument mapping training module. This module will include both individual analysis work and cooperative enquiry work, with the goals of developing the skills of analysis, evaluation, and inference, graphicacy skills, and generative knowledge search and knowledge import skills.

The second year of the programme would build upon the critical thinking and graphicacy skills students have acquired by providing instruction in the sciences of design, complexity, and action, specifically, by extending their cooperative enquiry to the collective design of problematiques, enhancement structures, and option fields that pertain to increasingly complex scientific and social problems. The second year would also include training in structural equation and system dynamics modelling and incorporate a focus on problems that require knowledge input from students working in disparate domains of science.

The third year of the programme would take students into the field, working on real-world social problems in collaboration with service learning and community based research faculty in the University. Students learn about the multidisciplinary nature of systems science and the very real challenge of implementing systems science in the context of real world problems. Students work with community stakeholder and content experts and become increasingly effective team members and applied systems scientists who come to appreciate the power and potential of collective intelligence and collective action, and the totality of their potential influence as a member of a team.

Notably, applied systems science seeks more than description and explanation of scientific problems. Consistent with the principles of functional contextualism, applied systems science seeks control over environmental contingencies that influence problematic situations (Chiesa, 1994; Skinner, 1972). However, when designing a systems science education curriculum, tasks and territories need to be manageable in terms of complexity, difficulty, and scale, such that students can bring about positive social change within their territory of influence within a reasonable timeframe (e.g., within a semester or a full academic year). Tasks are selected in partnership with community-based learning or service learning coordinators, and students advance their understanding of the science of design by learning how to use systems science tools in the context of team-based projects focused on real-world, ecologically valid tasks (e.g., how to improve volunteer satisfaction in the ‘meals-on-wheels’ service for older adults in Galway city). The ecosystem or territory of task activity opens students to the reality and complexity of local problems, but complexity is managed by selecting a sub-set of problems in the problem field (e.g., modeling interdependencies between the 12 most critical problems in a problem field and generating options to resolve fundamental drivers of negative influence in the problem field).

Training in applied systems science needs to begin in the classroom and focus on developing teams and talents and specific tool skills. However, there needs to be focus on meaningful tasks from the outset of training. Training might well begin with a classroom focus on description and explanation of both basic and applied science problems that are related in a very clear way to real world problems (e.g., modeling factors associated with community resilience based on a review of the empirical literature), but move from here to modelling similar dynamics with community stakeholders. In this way, cooperative enquiry and cooperative action come to be understood across the full spectrum of scientific activity, from basic to applied research to real world problem solving that must be conducted in a social and political context that places constraints on applied systems science and collective action.

We believe that the appropriate design and successful delivery of a systems science curriculum that embeds tasks in a territory outside of the classroom and exposes students to real-world project timelines and the potential stress and failure associated with real-world constraints on collective action, will facilitate the transfer, generalization, and reinforcement of both mastery and affiliation motive systems within the group. Mastery and affiliation motive systems are central to successful cooperative and collaborative dynamics and fundamental to successful problem solving in science and society. Cooperative relationships are characterized by reciprocity, mutual respect, discussion, perspective taking, and a coordination of each individual’s views with those of others (Wright, 1982). When students have the opportunity to share their views they are more likely to develop a stake in the process and therefore become motivated to learn and work toward common goals (Wells and Arauz, 2006).

Consistent with Warfield’s vision for systems science, Wells and Arauz (2006) argue that cooperative group work can be more productive than individual work. Group-generated knowledge can be a resource for individual understanding; individual understanding and action capacity can be a resource for the collective action of the group; students can revise their own perspectives in light of differing perspectives; higher-level collective and coordinated skill structures can derive from lower-level individual skill structures; coordinated perspectives can facilitate systems thinking along multiple paths of influence; sub-groups and individuals can focus on different aspects of a problematic situation and maximize the power of collective action.

In addition to further tool development requirement, there are a number of challenges moving forward, including the development of a deep understanding of how best to facilitate groups in both classroom and online learning environments, how best to train and prepare facilitators, and how best to increase the efficiency of working groups and possibly reduce the monitoring burden on facilitators using information technologies that support key processes (e.g., individual and group feedback) and the development of key products (e.g., models, simulations, reports, action agendas). Overall, we are very excited about the prospect for the development of a new applied systems science module that facilitates systems thinking, collective intelligence, and collective action focused on the resolution of an increasing variety of social problems. We also recognise that there are many challenges, but consistent with Warfield's view, we believe that these challenges and problems are the primary catalyst of creativity and the design of new solutions that help us to work together to solve shared problems.

References

Ackermann, F., Andersen, D. F., Eden, C., & Richardson, G. P. (2010). Using a group decision support system to add value to group model building. *System Dynamics Review*, *26*(4), 335-346.

Ackoff, R. L. (1981). *Creating the corporate future: Plan or be planned for*. New York: John Wiley and Sons.

Alberts, H. (1992, March). *Acquisition: Past, present and future*. Paper presented at the meeting of the Institute of Management Sciences and Operations Research Society, Orlando, FL.

Argyris, C. (1982). *Reasoning, learning, and action: Individual and organizational*. San Francisco: Jossey-Bass.

Ashby, W. R. (1958). Requisite variety and its implications for the control of complex systems. *Cybernetica*, *1*(2), 1-17.

Boulding, K. E. (1966). *The impact of the social sciences*. New Brunswick, NJ: Rutgers University Press.

Broome, B. J. (2006). *Applications of Interactive Design Methodologies in Protracted Conflict Situations. Facilitating group communication in context: Innovations and applications with natural groups.*: Hampton Press.

Broome, B. J., & Chen, M. (1992). Guidelines for computer-assisted group problem-solving: Meeting the challenges of complex issues. *Small Group Research*, *23*, 216-236.

Chang, N. (2010). Using Structural Equation Modelling to Test the Validity of Interactive Management. *Western Political Science Association 2010 Annual Meeting Paper*. Available at SSRN:http://ssrn.com/abstract=1580590

Chiesa, M. (1994). *Radical behaviorism : the philosophy and the science*. Boston: Authors Cooperative.

Checkland, P. B. (1989). Soft systems methodology. *Human systems management*, *8*(4), 273-289

Christakis, A. N. (1987). Systems profile: The Club of Rome revisited. *Systems Research*, *4*, 53-58.

Cleveland, H. (1973). The decision makers. *Center Magazine, 6,* 5, 9-18.

Coke, J. G., & Moore, C. M. (1981). Coping with a budgetary crisis: Helping a city council decide where expenditure cuts should be made. In S. W. Burks & J. F. Wolf (Eds.), *Building city council leadership skills: A casebook of models and methods* (pp. 72-85). Washington, DC: National League of Cities.

Deal, T. E. & Kennedy, A. A. (1982). *Corporate cultures: The rites and rituals of corporate life*. Reading, MA: Addison-Wesley.

Dwyer, C., Hogan, M.J., Stewart, I. (2013). An examination of the effects of argument mapping on students' memory and comprehension performance. *Thinking Skills and Creativity*, 8, 11 - 24.

Eden, C., and Ackermann, F. (2001). Strategic Options Development and Analysis - The Principle. In J. Rosenhead & J. Mingers (Eds.), *Rational Analysis for a Problematic World Revisited* (pp. 21-41). Wiley: Chichester.

Engelmann, T., Baumeister, A., Dingel, A., & Hesse, F.W. (2010). The added value of communication in a CSCL-scenario compared to just having access to the partners' knowledge and information. In J. Sánchez, A. Cañas, & J.D. Novak (Eds.), *Concept maps making learning meaningful: Proceedings of the 4th international conference on concept mapping, 1,* 377–384. Viña del Mar, Chile: University of Chile.

Engelmann, T. & Hesse, F.W. (2010). How digital concept maps about the collaborators' knowledge and information influence computer-supported collaborative problem solving. *Computer-Supported Collaborative Learning, 5,* 299–319.

Facione, J. (1990). *Critical Thinking: A Statement of Expert Consensus for Purposes of Educational Assessment and Instruction*: The California Academic Press.

Fischer, K. W., & Bidell, T. R. (2006). Dynamic development of action, thought, and emotion. In W. Damon & R. M. Lerner (Eds.), *Theoretical models of human development. Handbook of child psychology* (6th ed., Vol. 1, pp. 313 - 399). New York: Wiley.

Feeg, R. (1988). Forum of the future of pediatric nursing: Looking toward the 21st century. *Pediatric Nursing*, *14*, 393-396.

Forrester, J. W. (2007). System dynamics - a personal view of the first fifty years. *System Dynamics Review, 23*(2-3), 345-358.

Friend, J. (2001). The strategic choice approach. In J. Rosenhead & J. Mingers (Eds.), *Rational Analysis for a Problematic World Revisited* (pp. 115-150). Wiley: Chichester.

Harney, O., Hogan, M.J., Broome, B. (2012). Collaborative learning: the effects of trust and open and closed dynamics on consensus and efficacy. Social Psychology of Education, 15, 517–532

Heckhausen, J. (2000). Evolutionary perspectives on human motivation. *American Behavioral Scientist, 43*(6), 1015-1029.

Heckhausen, J., & Schulz, R. (1995). A Life-Span Theory of Control. *Psychological Review, 102*(2), 284-304.

Hogan, M.J. (2012). Well-Being in Ireland: Overcoming Barriers to Well-Being in Ireland, Conference Report, NUI, Galway.

Hogan, M.J. & Broome, B. (2013).Wellbeing in Ireland – Designing Measures and Implementing Policies, Conference Report, NUI, Galway.

Johnson, D. W., & Johnson, R. T. (2009). An Educational Psychology Success Story: Social Interdependence Theory and Cooperative Learning. *Educational Researcher, 38*(5), 365-379.

Keever, D. B. (1989, April). *Cultural complexities in the participative design of a computer-based organization information system*. Paper presented at the International Conference on Support, Society and Culture: Mutual Uses of Cybernetics and Science, Amsterdam, The Netherlands.

Kemeny, J. (1980). Saving American democracy: The lesson of Three Mile Island. *Technology Review*, *83,* 7, 64-75.

Kraemer, K. L., & King, J. L. (1988). Computer-based systems for cooperative work and group decision making. *ACM Computing Surveys (CSUR)*, *20*(2), 115-146

Kuhn, D. (2005). *Education for thinking*. Cambridge, Mass.: Harvard University Press.

Kuhn, D., Goh, W., Iordanou, K., & Shaenfield, D. (2008). Arguing on the computer: A microgenetic study of developing argument skills in a computer-supported environment. *Child Development, 79*, 1311 - 1329.

Maani, K.E and Cavana, R.Y. (2000*). Systems Thinking and Modelling: Understanding Change and Complexity*, Prentice Hall, Auckland.

Mikulincer, M., & Shaver, P. R. (2007). *Attachment patterns in adulthood: Structure, dynamics, and change*. New York Guilford Press.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychology Review*, *63*, 81-97.

Nunamaker, J. F., Dennis, A. R., Valacich, J. S., Vogel, D., & George, J. F. (1991). Electronic meeting systems. *Communications of the ACM*, *34*(7), 40-61

Piaget, J. (1952). *The Origins of Intelligence in Children* (M. Cook, Trans.). Oxford: International Universities Press.

Piaget, J. (1955). *The child's construction of reality*. [London]: Routledge & Paul.

Richerson, P. J., & Boyd, R. (2005). *Not by genes alone : how culture transformed human evolution*. Chicago ; London: University of Chicago Press.

Rittel, H., & Webber, M. (1974). Dilemmas in a general theory of planning. *DMG-DRS Journal, 8,* 31-39

Salas, E., Sims, D. E., & Burke, C. S. (2005). Is there "big five" in teamwork? *Small Group Research, 36*(5), 555–599

Sato, T. (1979). Determination of hierarchical networks of instructional units using the ISM method. *Educational Technology Research, 3*, 67-75.

Simon, H. A. (1960). *The new science of management decisions*. New York: Harper & Row

Skinner, B. F. (1972). *Beyond freedom and dignity*. London: Cape.

van Gelder, T. J., Bissett, M., & Cumming, G. (2004). Cultivating Expertise in Informal Reasoning. . *Canadian Journal of Experimental Psychology*, *58* 142-152.

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning: An historical perspective. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 409-426). Cambridge, UK: Cambridge University Press

Stein, Z., Dawson, T., & Fischer, K. W. (2010). Redesigning testing: Operationalizing the new science of learning. In M. S. Khine & I. M. Saleh (Eds.), *New Science of Learning: Cognition, Computers and Collaboration in Education* (pp. 207–224). New York: Springer.

Vennix, J. (1996). *Group Model-Building: Facilitating Team Learning Using System Dynamics*. Wiley, Chichester.

Warfield, J. N. (1974). *Structuring complex systems*. Columbus, Ohio,: Battelle Memorial Institute.

Warfield, J. N. (1990) *A science of generic design: Managing complexity through systems design.* Salinas, CA: Intersystems.

Warfield, J. N., & Cardenas, A. R. (1994). *A handbook of interactive management* (2nd ed.). Ames: Iowa State University Press.

Warfield, J. N. (2006). *An introduction to systems science*. Singapore: World Scientific.

Wells, G., & Arauz, R. M. (2006). Dialogue in the classroom. *Journal of the Learning Sciences, 15,* 379–428.

Werner, H. (1957). *Comparative psychology of mental development*. New York: International Universities Press.

Werner, H., & Kaplan, B. (1962). *Symbol formation*. New York: Wiley.