

Developing Systems Engineers

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Abstract--Systems engineering is a critical capability for our organisation's business following good growth in business but also because of risks in certain areas. Indeed, SE is of national importance if we are to sustain growth in the face of complex technologies. Ironically, there is a global shortage of these skills. This paper briefly reviews why it is difficult to develop SE skills and the current approaches used in industry considering their advantages and disadvantages. While the current approaches have proved useful, these are not producing enough systems engineers. Methods used in developing specialists in medicine at the University of Pretoria suggest a model for engineering faculties in developing systems engineers. Drawing on theories of cognitive and experiential learning, and learning from a social perspective an attempt is made to understand alternative methods for developing systems engineers. Against this backdrop, efforts implemented at the CSIR are described and preliminary findings reported. The key conclusion is that a balance between theory and practice is a vital accelerator in the development of systems engineers. Knowledge becomes *knowing* when it becomes the tool of action. This paper makes a number of important recommendations relevant to companies and universities.

I. BACKGROUND

Systems engineering (SE), which will be elaborated on shortly, is a critical capability for Defence, Peace, Safety and Security (DPSS), a unit of the CSIR, following good growth in business but also because of risks in certain areas. Indeed, SE is of national importance if we are to sustain growth in the face of complex technologies. Ironically, there is a global shortage of these skills.

For those readers who may not be directly involved in SE, it is worth noting that much of the paper focuses on learning and thus has a broader applicability. I consider learning for the development of systems engineers, but it is also relevant in the daily work of engineering and technology.

In order to focus the discussion and also because there has not always been consensus on what SE is exactly, the definition of the International Council on Systems Engineering (INCOSE) is used. It states [13]:

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem: Operations, Cost & Schedule, Performance, Training & Support, Test, Disposal, Manufacturing.

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both

the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

From this definition several issues are evident. Firstly, the scope of SE work is tremendous. Secondly, SE is typically performed by a group of people because on complex projects no one person has all the skills or time for all that is contemplated by the INCOSE definition of SE. Yet without adequate SE, projects have failed.

Once the required SE capability has been defined, there are a number of strategies for developing systems engineers. A commonly used one is to attend a commercial course presented by either local or international presenters. Some larger companies have developed in-house training. Using external training providers does not require the time of senior systems engineers and leaves attendees with good reference material. Joining INCOSE, an organisation concerned with disseminating SE principles and practices, is another way. The other common approach is on-the-job experience. Such development can be slow. Also, if not accompanied by relevant theory, it may not yield good results. A number of universities around the world have been offering SE courses. Many of these courses are introductory in nature but useful for getting an overview of the topic.

II. DEVELOPING SYSTEMS ENGINEERS – THE LITERATURE

Much of the literature on developing systems engineers has focused on characteristics and attributes of a systems engineer, SE at undergraduate level, and internal training programs and certification.

Davidz et al. have examined a specific ability of systems engineers, systems thinking, looking for enablers and barriers [7]. Three important enablers were identified in their research: 'Experiential learning'¹, individual traits and organisational design. Under experiential learning the authors list, amongst others, on-the-job-training and active mentoring but do not elaborate further. Others have focused on training based initiatives, relying on formal classroom time [10], [14]. Interestingly, Fisher [10] has added discussions on program related problems and lessons learnt in their organisational context to this classroom time. It is also evident that the evaluation of the quality of the training for the purpose of continuous improvement is important [14], [16]. Because it is well recognised that experience or on-the-job-training are important, albeit slow processes [7], there has been considerable debate within INCOSE and other organisations regarding certification as a means of evaluating SE experience [10].

¹ Davidz et al.'s (2005) use of experiential learning is in a generic sense and does not refer to the theory by the same name developed by Kolb (1984) and discussed later in the paper.

The feasibility of undergraduate university programmes for developing systems engineers has been a topic of contention for some years [11], [19]. In the US, SE programs at undergraduate and post-graduate level are being offered at over seventy institutions [9]. However, many senior systems engineers are sceptical that systems engineers can be developed at undergraduate level. While much of the literature discusses relevant subjects and outcomes, little attention has been focused on the fundamental issue of learning.

However as Davidz et al. [7] states: “*Most disturbing is that the interventions and methods organizations are using to address their need for more systems engineers are the same interventions and methods that rank at the bottom of the most effective interventions...*”. Many engineers have attended courses that they have never applied. The literature on developing systems engineers has not addressed why SE is difficult to learn. This paper hopes to show how undergraduate education can contribute to developing systems engineers if properly integrated with practice. Practice in the context of this paper means engaging in professional work. In the author’s view the focus should be on learning across the life of a systems engineer coupled with an ongoing battle against organisational barriers that prevent learning and application of SE in practice.

The following section considers why *learning* SE is difficult. Then, a review of a number of learning issues is undertaken, extracting key issues, to understand how to better develop systems engineers and facilitate learning SE follows. Methods used in our organisation and some initial results are presented.

III. WHY IS LEARNING SE DIFFICULT?

This section suggests a number of reasons why learning SE might be difficult. ‘Difficult’ in the current context relates to the nature of the material, skills and to the amount of time to acquire these in a useful way. Apart from SE knowledge, a basic understanding of a wide range of disciplines is required

for any SE application domain. While this application domain knowledge requires additional time to master, it is not considered as fundamental to learning SE for the purposes of this paper. Indeed much of the later discussion on learning SE could also be applied to acquiring basic mastery of these disciplines.

Young engineers sometimes struggle with SE because they cannot see the relevance. Inadequate understanding that *things can go wrong* on projects and then what *exactly can go wrong* on projects is usually the hurdle, based on the author’s experience and discussions with other systems engineers. While some of the issues may be explained, they may not be fully appreciated. This is perhaps the underlying reason why senior systems engineers feel that SE cannot be taught at undergraduate level. It is also for this reason that young engineers or students studying SE may inadvertently resort to *rote learning*, where new knowledge is simply memorised *without being integrated into existing knowledge* in long-term memory, simply to pass an exam [18]. This has been referred to in the management literature as a lack of ‘absorptive capacity’ [5]. Put simply, the more you know the easier it is to integrate into existing knowledge and therefore the easier it is to learn.

Many programs teach SE separated from the application domain in a way that is consistent with a positivist tradition of ‘de-contextualising knowledge’, i.e. knowledge that is context independent is more highly valued [22]. A given program may not be able to foresee every application and it is also easier to teach this way. But SE requires judgement under dynamic project conditions that are context dependant. Much of the knowledge required for this is tacit knowledge and therefore not easily transferred. Such knowledge is also not contained in standards which are almost always static. Fortunately, INCOSE has been sensitive to specialisation of knowledge in certain application areas. Accordingly it has formulated the technical matrix, illustrated in Figure 1, which presents SE enablers against application sectors. Yet even within these application sectors, there is a range of applicable knowledge.

		Application Sectors							
		Aerospace & Defense	Market Driven Products	Emerging Technologies	Enterprise	Information Systems	Infrastructure	Public Interest	Transportation
SE Enablers	Systems Science								
	SE Technical Process								
	SE Management Process								
	SE Support Process								
	Modelling & Tools								
	Speciality Engineering								

Figure 1 INCOSE's Technical Matrix

On the other hand senior engineers may not always be receptive to new approaches. Senior engineers have, through ‘experience’, formed beliefs and ‘theories’ which once formed are not easily changed [17]. In addition, it is likely that such beliefs will persevere even when there is discrediting evidence (and may even result in increased belief). Even when people discover that the evidence that they used to form a belief or theory is false, the belief or theory is likely to survive [17]. Also, information that is presented first is used to form a theory. Later information is added into the existing theory. If the later information is conflicting, it will be ignored or discounted. In other words, the sequence in which information is presented is important. This is the *primacy effect*. For example, people working on small projects early in their career are likely to develop processes more suited to these projects and thus form a ‘theory’ about how such engineering is undertaken because of the primacy effect. This ‘theory’ or approach to projects is likely to survive even when there is evidence that it is not suitable because of, for example, increased complexity. To work on large projects, such people would need to adopt new processes and skills which would be incorporated into their earlier view.

For engineers who are working, learning SE can be a problem because of work and cognitive loading. The size of the project or a shortage of people may lead to overloading. Project management or systems engineering failures, a lack of management commitment or resources may contribute or cause this overloading. The other type of loading which needs to be considered is cognitive loading. There is some evidence that certain forms of problem solving, such as means-ends analysis, and learning may be contrary goals [23]. Many engineering problems can be described as transformation problems containing an initial state (information about the environment, technologies and the problem), goal states (requirements) and a set of permissible problem-solving operators (discipline and application knowledge). Learning is concerned with the acquisition of schemata i.e. dynamic or relational aspects of memory structure [17]. But two interrelated mechanisms may interfere with this process: selective attention and limited cognitive processing [23]. Selective attention relates to the focus on the current problem state and the goal state while previous problem states and operators are largely ignored. For learning (schema acquisition) however, it is necessary to recognise a particular problem state as belonging to a certain category of problem states. Finding patterns and relationships across problems is thus important. The second mechanism interfering with learning is the cognitive load resulting from means-ends analysis. While this may be an efficient way of solving problems under most circumstances, it imposes a heavy load on limited cognitive resources. Thus a heavy emphasis on problem solving as the mechanism for learning may in fact retard learning.

Without adequate feedback, learning is difficult. For some projects there is a long time between when an activity is carried out and when the results are observed. This is an indicator of high task difficulty [24]. Schoening [21] states:

Human beings have considerable trouble recognizing cause and effect patterns over long intervals. Consider for example the time from when the requirements of a complex system are first defined to when the product is finally delivered to the customer; for some systems this can be over 10 years. In some cases regular delivery of prototypes can solve the problem, but this is not always possible.

The engineering of excellent systems does not depend only on having excellent individual systems engineers in the organisation. Systems engineers may interact with customers, various engineering groups, and management. Indeed, is the customer (or client) of a complex system not one of the most important stakeholder groups? This is a heterogeneous group in terms of organisational affiliation, background knowledge and objectives. Both the collective group and the individual require an understanding of SE. In the case of the individual, this understanding is *at a level appropriate to the role in the group*. What needs to be achieved is the creation of what Dixon [8] calls ‘collective meaning structures’, i.e. cognitive maps which the group members hold jointly. Collective meaning structures include norms, strategies and methods for dividing and performing tasks. While these might be codified as policies and processes, unless they simultaneously exist in the collective mind, technical and managerial coordination of work is impeded.

IV. DEVELOPING SYSTEMS ENGINEERS: IMPORTANT LEARNING ISSUES

In this section some important issues are presented from various perspectives including medical educational strategies, cognitive learning, experiential learning, and learning through practice for the purpose of understanding how to better develop systems engineers. Because of space constraints, this will not be a full review of any specific theory.

A. The Medical Educational Strategies

The investigation of medical educational strategies started with the observation that post-graduate students at the Medical Faculty of the University of Pretoria (UP) appeared to be using a practice-based approach. Challenges analogous to those being experienced in systems engineering were first observed in the area of medical education over twenty years ago. Melville and Johnston commented that “... *when the fledgling doctor emerges to confront the world of his patients the very process of becoming a physician will have rendered him incapable of dealing with the majority of problems that will face him.*” (Quoted in [12]). UP has applied the SPICES model, proposed by Harden et al. [12], for developing their medical curriculum. Some aspects of the model are useful to developing systems engineers and will be considered in SE terms at a relevant level of detail. The SPICES model is contrasted against traditional medical curriculum approaches in TABLE 1. These are two extremes on a continuum. Traditional approaches should not be completely abandoned in favour of the SPICES approach; rather a blend of the two is required.

TABLE 1 THE SPICES MODEL CONTRASTED AGAINST TRADITIONAL APPROACHES [12]

SPICES approach	Traditional approach
Student-centred	Teacher-centred
Problem-based	Information-gathering
Integrated	Discipline-based
Community-based	Hospital-based
Electives	Standard programme
Systematic	Opportunistic-apprenticeship

A teacher-centred approach revolves around the teacher with emphasis on formal lectures. Students have no control over what is learnt and learning tends to be more passive than active. Learning resources are prescribed by the teacher. With a student-centred approach, emphasis is on the students and how they learn. There has been increasing awareness that it is not what the teacher teaches that is important, but rather what the student learns [12]. In a student centred approach, students decide their learning objectives, select learning resources appropriate to the objectives and the pace and sequence of study, *under the guidance of the teacher*. The student evaluates his progress (discussed in the next section as meta-cognition) and when the student is ready, arranges for an evaluation. Student-centred approaches may better prepare and encourage students to continue learning throughout their professional lives because they have learnt to take responsibility for their own learning. However, many teachers and students have little experience with this approach [12].

In traditional medical schools the emphasis has been on transferring basic medical sciences and clinical information to the student. Once qualified, these students were then expected to synthesise all this information in the diagnosis and care of a patient. In medicine this information approach has yielded inadequate results and there has been a shift towards problem-based learning (PBL). PBL learning is a specific methodology developed by Barrows [1] and not simply solving problems at the end of the chapter. The purpose of PBL has been to integrate knowledge and to develop problem-solving skills.

PBL could also be used to develop SE skills. But there is a need for balance between PBL and the information approach. The information approach builds a vocabulary, an understanding of fundamental concepts and a framework providing an important foundation which would not necessarily be created with a problem-based approach only. But what are the 'problems' in SE? If we move away from the process centric approach to SE we could consider problems such as:

- Find a solution to the poorly defined problem X within certain time and schedule constraints.
- Although we have built a prototype solution, there is considerable delay and cost before we can build a second prototype like the first.
- A prototype has been fielded but it exhibits poor performance and does not 'work correctly' under certain conditions.

Following from this is integrated vs. discipline-based teaching. The integration is across the disciplines taught each year (horizontal integration) and across all the years of study (vertical integration). The purpose is to reduce fragmentation of courses and to move learning objectives from recall to problem-solving. In a discipline-based approach physiology, radiology, pathology, surgery, therapeutics and medicine were taught as different subjects. But in an integrated approach these same subjects are integrated around systems, such as the cardiovascular system. In medicine integrated teaching has been found to be more expensive than discipline-based teaching and has fewer resources to support it [12]. Today, much of engineering is discipline based. Only in the final year of undergraduate studies is there an attempt to integrate subjects in a project. I believe that moving toward an integrated approach is essential and lays the foundation for systems thinking.

There does not seem to be any question in medicine whether practice should be used in the development of doctors. The question revolves around whether the education is community-based vs. hospital-based [12], a question that is not relevant to the development of systems engineers. Electives vs. standard programmes in the SPICES model, concerned with study options, would best be considered in the detailed development of a SE curriculum and is not considered any further in this paper.

Systematic vs. opportunistic apprenticeship is concerned with getting exposure to a wide variety of specific experiences as opposed to limited or chance experiences that a student might get. In the traditional model, a student is attached to a supervisor and goes through all the patients in a particular ward. The specific cases that will be seen are unpredictable. In a systematic approach a programme is planned around the required capabilities and the clinical cases seen by students are logged. The systematic approach reduces exposure time and resources while an opportunistic approach may be simpler to organise and provides more continuity.

During vacations, engineering students are usually placed on a project under a supervisor. They will gather experience as far as opportunity allows. Even new engineers have to 'get on with the job'. A systematic approach could target specific projects or companies in order to achieve development objectives. For example, students might move between various processes such as requirements analysis to architecture design or across life-cycle phases such as production to maintenance and so on.

B. Cognitive Learning

From a cognitive point of view the most important factor influencing learning (apart from motivation) is what the student already knows [18]. This is the key to meaningful learning and the secret to avoiding rote learning. When a diverse group is learning SE, there can be great variability in what each person knows at the start (recall the heterogeneous group referred to earlier). For learning to be effective, relevant existing knowledge, including misconceptions must be identified. Only then can the new knowledge can be organised and sequenced for learning in a way that can be

integrated into existing knowledge. Novak [18] has proposed using concept maps, similar to entity-relationship diagrams in engineering (Figure 4 is an example of a concept map), to explore existing conceptual and propositional knowledge. This requires interaction between the coach and the student. Thus, there cannot be a curriculum with only fixed content.

In recent years meta-cognition, which is concerned with ‘thinking about thinking’, has received considerable attention [2]. In the context of learning it would be concerned with monitoring the learning process, being persistent, finding relationships in data, and seeking additional information. Meta-cognition is critical for the learner to make progress. The coach must stimulate development of the student’s meta-cognitive processes with questions, like ‘How do you know that?’ or ‘What additional information do you need?’ Meta-cognition is important for learning *about* SE. Since SE involves cognition, meta-cognition is also important for *being* a systems engineer.

C. Experiential Learning

Experiential learning, the process of creating knowledge through the transformation of experience, offers a number of insights that are useful in developing systems engineers [15]. Firstly, *learning is a process and not an outcome*. Ideas are formed and reformed through experience. Students are not merely containers of knowledge to be filled by teachers. Klob sees learning as a continuous process grounded in experience. Specifically, learning occurs in the interaction between expectation and experience. When the engineer builds a model believing that it is correct only to discover that it is not, the stage is set for learning. Since learning is a continuous process, we never start with a ‘clean page’. There

are always preconceptions or ideas, some right, some wrong (and I have seen this in my coaching). The ones that are wrong must be re-learned. Others might need to be refined. But these ideas are there. Thus the role of the teacher or coach is not only to impart new knowledge, but to correct ‘wrong’ ideas.

Learning requires resolving conflicts between dialectically opposed modes of adaptation to the world, namely, concrete experience, abstract conceptualisation, active experimentation and reflective observation (Figure 2). The concrete experience/abstract conceptualisation dimension, represents how we grasp experiences in the world, which can be either through tangible, sensory perceptions or through conceptual interpretation and symbolic representation. Concrete experience is personal and not easily shared. The other dimension represents how we transform our grasp of the world. This can be done by reflective observation on the one hand or by active manipulation of the external world or active experimentation on the other hand. Knowledge then, as Kolb puts it, “*results from the combination of grasping experience and transforming it*”. Thus learning does not happen with only a grasp of experience or transformation alone. So for example, transformation must act on some state or experience while experience without action does not constitute learning.

The amount of concrete experience and active experimentation are reduced when teaching SE in a traditional classroom, either at a university or in the workplace. Even if one is able to observe a real requirements elicitation session, for example, it is unlikely that one would be able to participate. Active experimentation requires interaction with the world which is not always practical unless supported through practice.

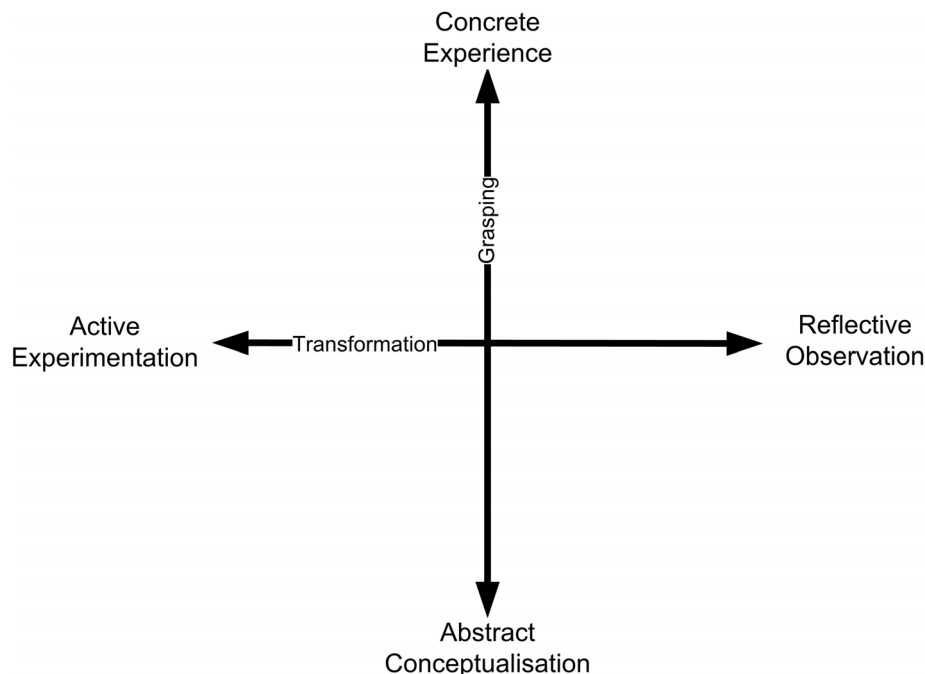


Figure 2 Structural dimensions underlying the process of experiential learning [15]

D. Learning through Practice

It could be argued simplistically that learning through practice is nothing more than on-the-job-training or no different than experiential learning. But *any* on-the-job-training will not necessarily achieve results. Neither cognitive learning nor experiential learning considers *social* issues that must surely be important for learning. While experiential learning requires concrete experience, this could be within a simulated or a real context. The issues that will be discussed briefly in this section are situated cognition, transfer of tacit knowledge, negotiation of meaning through participation and identity.

One of the emerging concerns of formal SE education, and indeed most professional education, is that it de-contextualises what is learnt from how it is used [22]. It is like learning to speak a foreign language using a dictionary

[3]. The context and conditions for the application of what has been learnt can only be fully understood through practice. Formal education is based largely on the premise that knowledge can be represented, i.e. explicit knowledge. Explicit knowledge is readily communicated. As was alluded to earlier, there is some tacit knowledge that can not be described explicitly. Tacit knowledge is not easily verbalised. For example, one cannot give a lecture on riding a bicycle, and expect students to ride on their first attempt. It is only when we interact with the bicycle, in an intensive way that we learn [6]. Such tacit knowledge may reside in an individual or group (Figure 3). Just as one can acquire a tool (like a hammer or a piece of software) without using it, sometimes it is only when we try to apply our knowledge that we realise that something is missing. When knowledge is used as a tool *in action*, it becomes knowing [6].

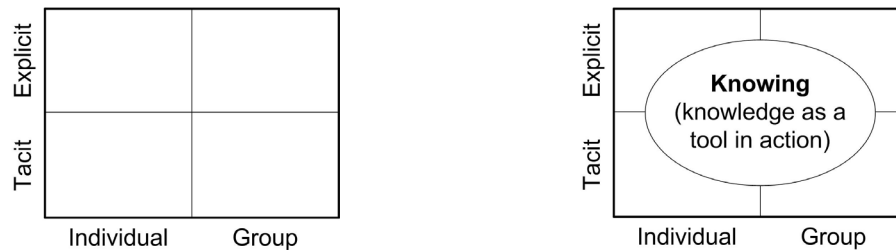


Figure 3 Four forms of knowledge (left) and the same knowledge in action (right).

Knowledge is largely transmitted as a social process of negotiated meaning [25]. ‘Negotiate’ here is in the sense of ‘negotiating a sharp bend’. Meaning is derived through participation in practice and from tangibles such as documents, books or tools in what Wenger refers to as ‘reification’ (to treat something as substantially exiting or as a concrete material object). In SE we tend to focus on the tangibles. This is not without reason: explicit knowledge can be more easily managed. But, participation cannot be substituted by reification and vice-versa. As Wenger says [25]: “...reification always rests on participation: what is said, represented or otherwise brought into focus always assumes a history of participation as a context for its interpretation. In turn, participation always organises itself around reification because it always involves artefacts, words, and concepts that allow it to proceed.”

In order to understand individual learning in the context of practice, it is necessary to touch on identity [4], [25]. One might think that learning is concerned with acquiring knowledge – this is so. But learning is important in acquiring identity. One cannot simply claim to be a doctor. Other doctors must recognise you as a doctor, whether they speak as colleagues or as representatives of society. Thus learning is

not only about acquiring knowledge, but our identity *impacts what knowledge we will acquire* and to which communities we can belong. Members of such a community have a common purpose and membership allows learning. Our daily relationships define ‘who one is’ in terms of who knows what, who is helpful and who is good at what. The learning is facilitated by shared practice. Thus sharing stories within the community is important. Allowing newcomers to participate, without the organisation or the newcomer necessarily taking risks, is important (what Wenger calls *legitimate peripheral participation*).

Practice is the most valuable resource for learning, not material derived from it where the context and meaning have been lost. Knowledge is transferred through a social process of negotiated meaning. Assessing whether knowing has been achieved, requires application of knowledge, not only as an individual but as group. Plans and schedules (reification) for developing systems engineers combined with participation are important; participation is initiated through the removal of organisational barriers. The application of some of these learning issues to develop systems engineers is discussed next.

V. DEVELOPING SYSTEMS ENGINEERS AT DPSS: SOME INITIAL WORK

This section discusses some of the initial work in developing systems engineers at DPSS. The initial objective was to improve SE skill across the unit with special attention on requirements analysis and to encourage the application of SE on projects where it was relevant. An important consideration was to develop SE capability within each of the technology areas. A multi-faceted approach was used, including:

- A commercial SE course,
- Facilitated group discussions within some areas of DPSS,
- One-on-one Coaching, and,
- SE tool training (certain individuals).

Each of these methods is discussed in more detail in the following sections.

A. SE Course

The formal course was aimed at creating a sensitivity to SE and transferring information, creating a common language and framework. The specific course was selected because of its focus on 'how to' rather than just 'what' (process). A total of 50 people attended this one week course. Of particular importance was sensitising managers because they control resources. For this reason, a number of managers were also on the course although it is not expected that they will apply the techniques directly themselves.

Feedback from staff that attended the course was overwhelmingly positive. However, if people were not able to bridge the gap between the course, with its volumes of new concepts, and practice the course would be ineffective in improving SE skill. The following section deals with bridging this gap.

B. Facilitated Group Discussions and One-on-one Coaching

The one-on-one coaching and facilitated group discussions were aimed at the development of skill. Facilitated group discussions were started in some areas aimed primarily at people who had attended the SE course and facilitated by a member of the SE Group (of which the author is a member). Essentially these are communities of practice for each area [25]. These were in the form of a scheduled half hour meetings on a weekly basis for the purpose of coordinating one-on-one coaching meetings and sharing experiences in applying SE *on projects*. These half hour meetings were extended when there was a need for longer discussions. The half hour sessions form a point of focus (reification) that allows for participation. Learning occurs in a context that is meaningful for the participants.

Colleagues were introduced to concept mapping [18]. This tool was then used to facilitate some sessions. In one-on-

one coaching concept mapping helped some colleagues realise that they did not understand some of the concepts as well as they thought they did – a meta-cognitive experience.

The success of these two methods varied. In one area, the course and one-on-one coaching methods are contributing to learning and a positive attitude towards SE. People have seen value in applying SE concepts. On one project the project manager from the client organisation also participates in the group sessions. In a second area, scheduled weekly meetings were cancelled because of poor attendance. Reasons for this are discussed in section D.

C. SE Tool Training

SE tools can be used as a method of increasing SE skill. The purpose of SE tool training was threefold:

- Create awareness of SE tools and why such tools should be used,
- Use the tool and its embedded SE knowledge for transferring skill, and
- Increase the number of people able to use SE tools on projects.

Because of some difficulties in accessing international training for the tool, we developed a basic one-day interactive course using a traffic light system as an example. Although this is an almost trivial example, it serves to highlight the need for modelling. It also helps to make abstract SE concepts more concrete. A total of 7 people have been on this course and of these at least 3 are actively using the tool. Combining the tool use with facilitated group discussions has led to a number of insights on projects in one of the areas.

D. Issues Observed During Coaching

Some issues observed during this first attempt were:

- Coaching should be aligned with the start of the project where SE will be applied.
- Because the personnel recruitment rate has not matched business growth, we have been experiencing a shortage of people. This has led to over-loading, especially amongst more senior staff with management responsibilities. Thus this group has not been available for coaching.
- Some areas require better resource management in order to stabilise the environment and thus make it more conducive to learning.
- There are a small number of people that believe that projects are more important than learning related activities. Although they attended the training, they were not interested in coaching.

As Wenger [25] has pointed out, one cannot design learning; one can only remove obstacles.

E. Survey Results

A survey of people who were involved with any of the methods was conducted. The questions covered the effectiveness of the methods used for developing systems engineers, application on projects, and the environment in which SE is being applied. The survey response rate was 26.5% out of 50 questionnaires sent out.

Starting with the effectiveness of the methods used for developing systems engineers, each of the methods was evaluated in terms of information and skill transfer. TABLE 2 summarises perceptions of which methods work best. The mean, standard deviation and sample size are indicated for each of the four methods in the information and skill categories. Skill was defined as the ability to apply techniques on real projects. In general, respondents rated the

SE course higher for transferring information than skill. This result is statistically significant at the 5% level. While this result was not unexpected, the small difference of 1.5 in the effectiveness of the SE course in terms of information transfer vs. skill transfer (8.5 vs. 7.0) is somewhat surprising. The expectation that this difference should be larger is supported by observations in one-on-one coaching sessions where it was clear that some of the SE concepts are not understood. While the survey did rely on perceptions, it is possible that the survey instrument was inadequate or that respondent’s self-assessment of learning was inaccurate - an issue of meta-cognition. For other cases in TABLE 2 the number of responses was too low to be able to draw statistically significant conclusions. However, all the results are positive and indicate the potential of the methods.

TABLE 2 EFFECTIVENESS OF METHODS AS ASSESSED BY SURVEY

	Transferring information				Transferring skill			
	SE course	Facilitated group discussions	one-on-one coaching	SE tool	SE course	Facilitated group discussions	one-on-one coaching	SE tool
Mean	8.5	8.0	7.7	6.6	7.0	7.0	8.0	6.8
Std. D	0.9	1.4	1.2	0.5	1.6	1.0	1.0	1.6
N	13.0	4.0	6.0	5.0	12.0	3.0	7.0	5.0

The responses regarding application on projects, the environment and recommendations have been roughly clustered in Figure 4. The proportion of people making a recommendation is indicated in parentheses. Since the SE course focused mostly on requirements analysis, this has also been the largest application area. But even then there is still scope for the application of tools like functional analysis in requirements analysis. The most commonly cited benefits of applying SE on projects, were a holistic approach to engineering and being more thorough. Interestingly, SE as risk management was not raised by any respondents. In terms of the environment, one of the biggest factors preventing the application of SE is overloading or a shortage of people, according to respondents. Recommendations for more training and coaching were made. It is also interesting to note that some respondents thought that their clients would benefit from awareness of SE.

F. Conclusions and Recommendations of the DPSS Study

We believe that the SE course has been successful in terms of creating sensitivity to SE. It has also raised the importance of SE and made it a topic of discussion. This is itself important in terms of effecting change. When supported by facilitated group sessions and one-on-one coaching, the

combination has been shown to yield results in certain areas in our organisation. It is especially facilitated group discussions and one-on-one coaching that creates the framework for applying the learning issues. The SE tool is a method of increasing intensity of interaction with the material. Because the SPICES model was only discovered late in this study, its ideas were not applied. For example, the application of systematic apprenticeship needs to be more fully explored.

However, organisational barriers such as lack of resource management have contributed to poor results in other areas. The following recommendations are based on issues observed by the author and survey feedback:

- Where resource management is not properly applied, it should receive attention first to stabilise the environment before coaching is undertaken.
- While much of the application has been in the area of requirements analysis (and this area still needs more attention), there is also value to be unlocked in terms of architecture design. Combined with the alignment of coaching to the start of projects will require efforts over a number of years.
- Involve our clients in appropriate SE learning.

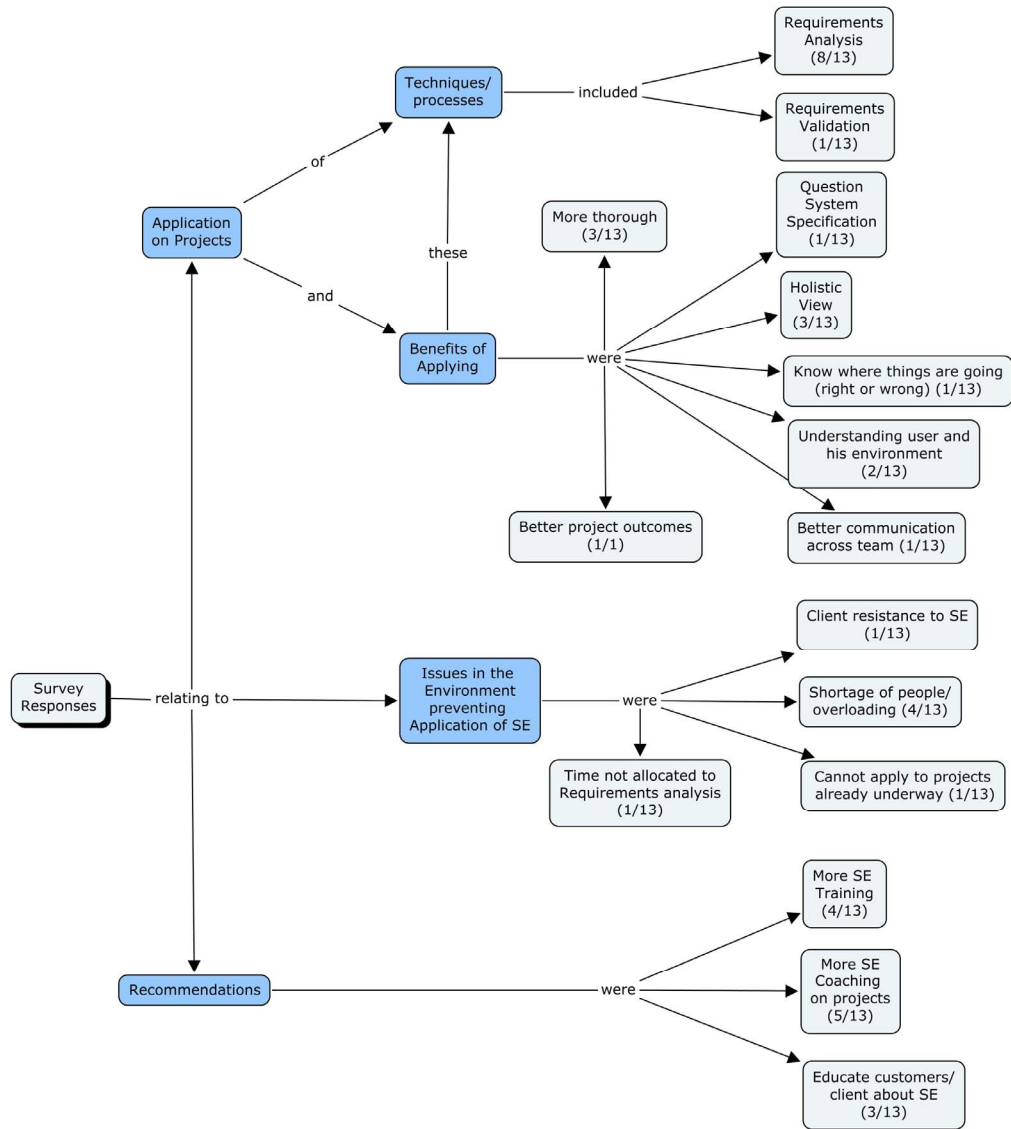


Figure 4 Clustered survey responses relating to application on projects, the environment and recommendations

VI. CONCLUSIONS

There are many challenges to developing systems engineers. Looking from a learning perspective, there are a number of areas where more can be done. Presenting SE at university has value in terms of creating vocabulary and frameworks of knowledge. Universities must go further in terms of integration of disciplines and incorporation of practice as a means of learning. SE students need to participate in practice on a regular basis. Without this students will resort to rote learning instead of meaningful learning. Transitioning from the theory to practice may benefit from the introduction of PBL and case studies. Systematic exposure to practice is necessary to develop the required profile of experiences. If we are serious about accelerating development of systems engineers we need to

move from methods that are low cost and reduce workload for lecturers to methods that are focused on student learning.

From a SE point of view, some of the undervalued aspects of practice are the negotiation of meaning through participation and the relationship between participation and identity. Documents, books and even specifications cannot by themselves contain all meaning, for example. Experiences grasped must be acted on and action must transform some experience. Thus we cannot claim experience if we continue to make the same mistakes. Practice is essential for the transfer of tacit knowledge required to handle the dynamic project environments of the real world. Knowledge becomes knowing when it becomes the tool of action.

A careful balance between practice and theory is necessary. These do not represent opposites, but interdependent ideas. One cannot have practice without

theory and one cannot do research without practice. This requires closer collaboration between universities and industry with regard to SE. Spending time on learning is counter-intuitive since it reduces time for work. However as Repenning and Sterman have pointed out [20], in order to increase productivity, we need to spend time improving, or learning as it has been referred to in this paper. Since what is being proposed here is resource intensive, some future work being considered is profiling of candidates as a selection mechanism.

There seems to be a fundamental belief held by many educational organisations that formal, de-contextualised knowledge has more value than the informal, situation specific knowledge that the systems engineer must wrestle with in daily practice. This belief and the culture that propagates it means that the types of changes required to accelerate the development of systems engineers will not be easy to implement. But learning as a formal activity is only the start. If SE is a group activity and this group is only formed at the project start, then learning can only be completed in the workplace (if ever) since it depends on the group members, the nature of the project and the inter- and intra-organisational environment. It is for this reason that the learning issues raised here are so important.

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