Screening Candidate Systems Engineers:

A Research Design

Duarte Gonçalves
+27 12 841 3963
dgoncalv@csir.co.za

Janine Britz
+27 12 841 3873
JBritz@csir.co.za

Council for Scientific and Industrial Research (CSIR)
P.O Box 395
Pretoria, South Africa
0001

Abstract. In this paper, we focus on the human dimension of Systems Engineering by addressing the need for the development of systems engineering potential in candidate engineers. Specifically, we propose a research design for a systems engineering screening methodology that could be used to screen potential systems engineers. According to our design, this can be achieved by defining a system engineering profile with specific psychological attributes, and using this profile to predict competence in systems engineering. This is done with the aim of increasing the identification and successful development of systems engineering potential, in order to address the shortage of systems engineering skills in South-Africa over a long-term period.

1 Introduction

Internationally, there appears to be a shortage of Systems Engineering (SE) skills. As Professor Peter Lindsay of the University of Queensland (Australia)[1] said: "The existing international shortage of systems engineers is likely to double in the next few years". This is a problem, specifically in South Africa, where organizations such as the Council for Scientific and Industrial Research[2] (CSIR), formed by an act of parliament in 1945, have a great demand for these skills. The Defence, Peace, Safety and Security (DPSS) unit of the CSIR provides defence science and technology support to the South African National Defence Force and various international customers. This unit has experienced growth of 30% in some business areas for a number of years leading to significant demand for SE skills.

Various strategies, which will be discussed in the following paragraphs, are employed in order to address the shortage of SE skills. However, these strategies are not always fully effective (Davidz and Nightingale 2007), specifically in the context of DPSS. We explore what they are, and propose reasons for why they are ineffective. We also explore and highlight certain problems with the demographics of systems engineers (SE's), specifically in the South-African context.

Strategies employed for developing SE skill begin at University level, with SE educational programmes. However useful, these programmes alone are not completely effective - knowledge alone cannot ensure success when working on SE projects – skill and experience

[1] http://www.uq.edu.au/news/?article=4949
[2] http://www.csir.co.za/

are also important (Davidz and Nightingale 2007).

In the organizational context, the most obvious strategy employed in DPSS, is the recruitment of SE's, which only addresses a short-term need. In 2006 and 2007 DPSS was unable to recruit any new systems engineers. While 4 systems engineers were recruited in 2008, they were all white males. The alternative to recruiting systems engineers, is the development of candidate systems engineers through intensive training and coaching programmes (Gonçalves 2008). Although this strategy certainly addresses the long-term need, it is not always effective as some candidates do not have an *interest* in SE, and others simply do not have sufficient *potential* to perform SE tasks and activities. In other words, they do not possess certain desirable *attributes* that would better allow them to perform these tasks and activities competently (discussed in more detail in section 3). Thus, despite the effectiveness of the development program itself, internal candidates do not always develop SE knowledge and skills successfully, in our experience.

In the South-African political context, the development and employment of individuals from diverse cultural, ethnic, and race groups is an important goal. This is also the case in the CSIR as a government funded organization. However, most SE's in South Africa are white males. Additionally, most SE's in DPSS are over the age of 40. When striving to achieve diversity, these demographics present a problem.

The value of screening potential systems engineers, specifically with regards to addressing a long-term need for systems engineering skills, is discussed in section 2. Section 3, reviews the main contributions from the literature regarding this problem, as well as some gaps and limitations that we propose to address. We identify a framework for assessing competence in *potential* SE candidates based on this literature. Section 4 formally defines the problem (research question). In section 5 a plan is proposed to address the problem (research methodology), and the current status of our research is discussed. Our conclusions involve our observations of what the problem is, and the approach we take in solving it.

2 Screening Value Proposition

The business value of screening lies in the cost currently incurred because of the shortage of SE's and the lead time in developing SE's. The current costs resulting from this shortage includes:

- SE recruitment costs include advertising, interviewing costs and recruitment agency fees
- Training and coaching costs resulting from candidates who don't develop successfully
- Opportunity cost resulting from not being able to access new projects, and
- Project risk, a consequence of not having the adequate skills on current projects.

Activities on projects are the vehicle for competency development (Leonard-Barten 1998). Since we are typically talking about larger projects over more than a year, there may be limited opportunities. These opportunities are thus a development resource. Apart from this, development also requires time from more senior systems engineers for coaching. Thus, developing engineers that have sufficient potential can ensure the better allocation of company resources.

As previously mentioned, there is also a lead time. If we assume a basic engineering degree and 3 years practical experience, then systems engineering development could start at the age of approximately 25. If we further assume that the development time will be about 5 years, this puts the earliest age that we could have junior systems engineers at 30.

The main and underlying value in conducting our study thus lies in addressing the shortage and quality of SE's *over the long-term*. Our approach to the development of SE's will benefit the organisation as it ensures better strategic employment of staff – the organisation would be able to employ candidates who have the potential to become SE's.

Apart from this value, there are also additional screening benefits resulting from the assessments. Engineers could use the assessment results for personal growth and increased self-awareness, to better understand how their colleagues would behave in the work context, and to increase their general awareness of SE. Coaching could be tailored to the learning preferences identified during the assessments to ensure more effective development of candidates. It can thus be seen that these benefits reflect psychological value.

The results of the literature study will be discussed in the following section as a prerequisite to formulating the research question.

3 The Literature: Assessment of SE's and the SE Profile

We start by reviewing a general competency framework from the literature and, based on this, we review constructs in the literature relevant to screening potential SE's in more detail.

In Figure 1, we present a model that constitutes the constructs that are important considerations in the assessment of competence (Brannick and Levine 2002; Cognadev International). *Competence* is defined as the necessary ability, which consists of talent and skill, to do something successfully. It depends on knowledge, skill and various psychological attributes (Figure 1). For the purposes of this study, *assessment* is defined as the *measurement* of psychological attributes, knowledge or skills. Therefore, in order to determine SE competence, one should assess all of these constructs.

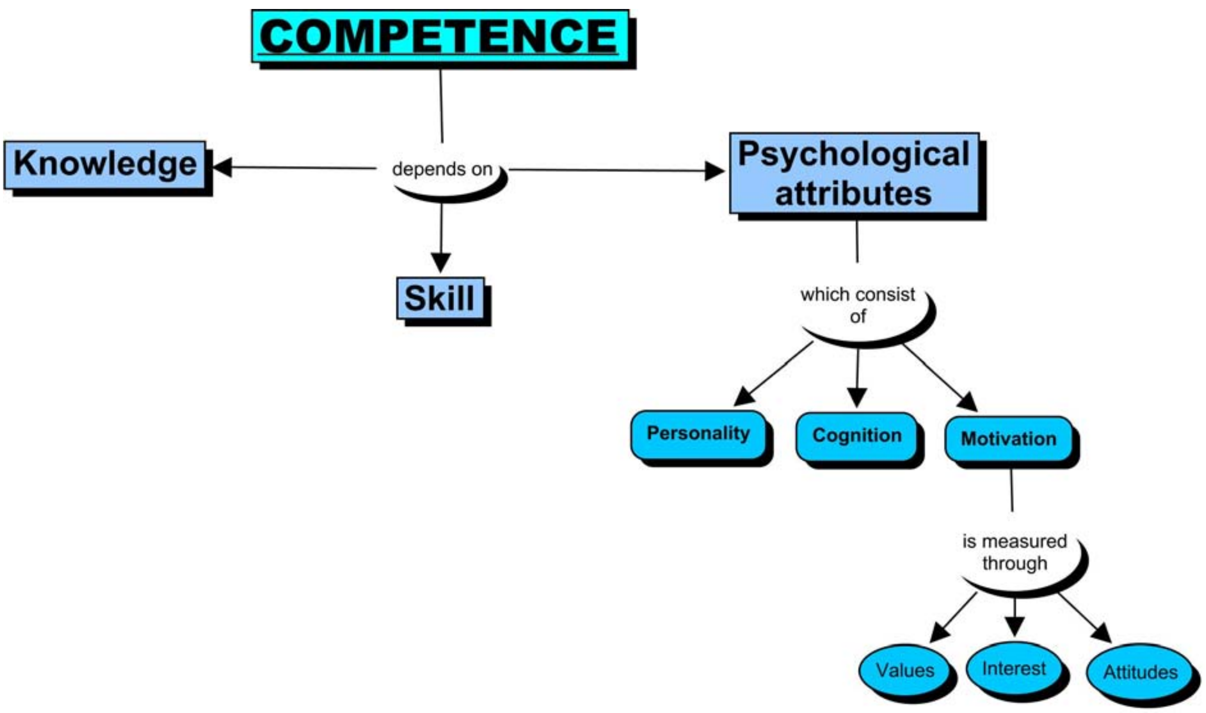

Figure 1. Assessing Competence

In SE, knowledge can be learned. A person without natural potential may not be able to perform certain SE tasks and activities *successfully*. i.e. would not have or be able to develop the requisite *SE competencies*. For SE's a simple interview would identify whether the person has the requisite knowledge and skills. The situation is more complicated for candidate SE's, however, as they would not yet have fully developed knowledge and skills. Thus *we focus on candidate potential in terms of the psychological attributes only*. It can be seen from Figure 1 that motivation consists of values, interests, and attitudes. However, we are most interested in values because these are most stable over time (George and Jones 1997): "work attitudes, as knowledge structures, should exhibit a certain degree of stability, but not as much stability as values because one of the functions of attitudes is to help the individual adjust to changing conditions over time and stay attuned to the social context". Thus, in terms of motivation, we focus on values for the remainder of the document.

It is important to gain insight into what has been done before regarding the assessment of personality, cognition, and motivation in SE's, and to build our current study on the previous literature. From previous studies, a significant number of contributions have been made. These contributions include the generation of a number of SE personality characteristics and cognitive abilities (psychological attributes) listed in Table 1, as well as insight into the use of a variety of psychological assessment measures to assess SE's.

Table 1 presents a selected list of the most relevant SE psychological attributes identified from the literature. This list has been categorized into intra-personal attributes (relating to self) and inter-personal attributes (relating to interaction with others), and has been clustered to show the quantitative interrelation between these characteristics and abilities (as some may overlap). As previously mentioned, we would not expect candidates to show *ability* relating to the attributes identified in Table 1, but would expect them to show *preference* relating to these attributes.

Table 1 : Personality characteristics & Cognitive abilities (Marais 2004, Toshima 1993, Kobori 1991, Capretz 2003 and Frank 2006)

Intra-personal	**Inter-personal**
Intellectual curiosity	**Sociable** - good communicator
Ambitious - hardworking, dedicated, persevering	**Forward** - willing to ask challenging questions, speak mind
Innovative - creative, concept generation	**Self-motivated** - achievement motivation, able to motivate others
Rational, **logical and analytical**	**Leadership skills** - assertiveness, coordination skills, confidence
Organized and responsible	**Persuasive**
Strategic	**Patient**
Flexible and **adaptable** - comfortable with ambiguity	
Big picture thinking - understanding the whole without getting stuck on the details	
Systems Thinking - understand relations between parts of a system	

Apart from these contributions identified from the literature (such as the list of psychological attributes, listed in Table 1), certain limitations and gaps have also been identified. In terms of the assessment model, there does not appear to be literature on SE-psychological attributes holistically - the focus is mostly either on personality or cognition. Literature on values or other motivational constructs in the context of SE is limited. Furthermore, the list of characteristics and abilities identified in the literature are not linked to individual SE competencies, and a *quantitative interrelation between attributes and SE competencies has not been shown*. For example, are the same psychological attributes required for requirements analysis, modelling and simulation and configuration management? We believe there will be differences.

We attempt to address these limitations and gaps in our research study, by formally defining the problem in the following section.

4 Defining the Problem

From the previous sections, it is clear that a method is needed to address the shortage of SE's over a long-term period, and to select candidates with adequate SE potential for development (in different cultural, ethnic and population groups). We propose a research study that will address the shortage of SE's over the long-term, by designing and validating a methodology for screening candidates with SE potential for development. This could lead to the development of potential in younger engineers, female engineers, and engineers from different cultures and races in South-Africa.

In our study, the *SE profile* is an indicator of potential to perform SE competencies. This profile constitutes the psychological attributes of the model (i.e., a psychological dimension), in other words, **personality**, **cognition**, and motivation in terms of **values** (Figure 2). It is important to note here that we would assess potential candidates according to their *preferences* for certain psychological attributes, not abilities, as these would not be expected to have fully developed in candidates. Furthermore, we would identify relevant scales and the *range* of values on each attribute and that constitute the SE profile (rather than a single ideal profile). This profile should predict SE competencies (i.e., a SE dimension).

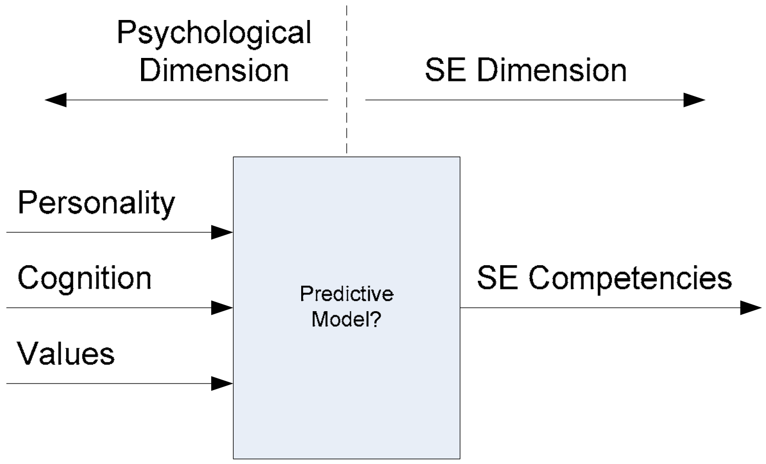

Figure 2 Predicting development of SE competencies from psychological attributes.

This can be summarized in our **basic research question**:

> *Can the successful development of SE competencies be predicted from personality preferences, cognitive preferences and values (the SE profile)?*

The rationale for this question is supported by the theory that job performance and job satisfaction depends not only on knowledge and skills, but **personality** (Foxcroft and Roodt 2005), **cognition** (Lent and Brown 2006) and **values** and **attitudes** (George and Jones 1997, Schaubroeck, Ganster and Kemmerer 1996).

Given the research question, we develop a research methodology in the following section.

5 Research Methodology

We start by considering the *design* of a screening methodology (phase 1, discussed in section 5.1). Since our research question (identified in the previous section) deals with predicting successful development of systems engineers, the screening design needs to be followed by *validation* of the screening methodology (phase 2, discussed in section 5.2). In other words, to answer our research question, two different hypotheses would need to be tested, which constitute the two different phases of the study. In the *screening design phase*, we test the hypothesis:

***H_1**: The level of SE competencies can be predicted from personality preferences, cognitive preferences, and values (the SE profile).*

While the level of SE competencies also depends on knowledge and skills, this is not directly relevant because our focus is on development of *potential* systems engineers.
The purpose of the *screening validation phase* is to test the hypothesis:

***H_2**: Successful development of SE competencies is predicted from engineers with the SE profile.*

We define "successful development" as an increase in SE competency beyond natural development on projects, using training, coaching and facilitated workgroup sessions (Gonçalves 2008). During screening validation no 'reject' decisions will be made, i.e. nobody will be turned away from development based on their assessment. The reason for this is an ethical one: at this point our screening methodology has not been shown to be suitable for this purpose.

In the following sections, we describe the processes and aims in the screening and validation phases of our study in more detail.

5.1. The Screening Design Phase. In this phase, participants will be assessed according to their personality preferences, cognitive preferences, values and SE competency. We have identified the assessment measures to be used which appear to be relevant to the purpose of the study (Gonçalves and Britz 2008) based on:

- The research question
- Characteristics of systems engineers defined from the literature in Table 1
- The context in which the screening is proposed.

The relevance of the assessment measures will however be confirmed by the data. To assess cognitive preferences, we will use the Cognitive Process Profile (CPP feedback manual, Cognadev International). The CPP is an advanced computerized assessment technique designed to measure thinking processes and styles and to link this to everyday cognitive functioning (Cognadev International). For the assessment of personality preferences, the 15

Factor Questionnaire Plus (15FQ+ Technical Manual, Psytech Ltd.) has been identified. The 15FQ+ is a personality assessment measure that assesses a number of personality traits on 21 scales. Finally, values will be assessed using the Value Orientations (www.cognadev.com). The VO measures individuals' value orientations, i.e. which value systems they accept and which they reject. For the purposes of this study, value systems are defined as: "A value system is a generalized knowledge structure or framework about what is good or desirable which develops over time through an individual's involvement in the world. A value system guides behaviour by providing criteria that an individual can use to evaluate and define actions and events in the world surrounding him or her. An individual's personal set of values determine which types of actions and events are desirable or undesirable" (George, 1997, p.395). A detailed discussion of the selection of these assessments is outside the scope of this paper but can be found in our research proposal (Gonçalves and Britz 2008). SE competencies will be assessed using an adapted version of the *Systems Engineering Competencies Framework* (INCOSE UK 2006), a model that categorizes twenty one SE competencies into three broad categories: Systems Thinking, Holistic Lifecycle View, and Systems Engineering Management. This framework has been implemented as an excel questionnaire where candidates can evaluate themselves on each competency. According to their answers, one can then determine their level of SE competence (Awareness, Supervised Practitioner, Practitioner or Expert). Engineers in DPSS will be assessed using these four assessments.

The sample which will be assessed in the study will be engineers with at least three years experience, including systems engineers, and other engineers (OE's) from various gender, age and population groups. OE's are engineers who are not currently systems engineers. The engineers will be randomly selected to prevent bias. A broad sample of engineers is required in order to evaluate whether SE's can be identified from OE's (based on the SE competencies questionnaire). Thus, we should be able to separate a SE profile from an OE profile. If this cannot be achieved the study is terminated. It is important to note that in both these studies, the sample would consist mostly of OE's to retain the same proportions as the engineering population (the *sample* must be representative of this *population*). Additionally, the majority of engineers in the sample would be white males for the same reason. This is one of the challenges of the current study. The estimated sample size required is 100 engineers, based on the number of scales on the psychological dimension and data analysis considerations.

In the analysis of the assessment results, the psychological dimension will be used to build a model which separates engineers with the SE profile from those with the OE profile, which will be referred to as a discriminant function. In building this model we will not assume that all dimensions of personality, cognition and values are all important, i.e. we will test relevance to establish the criteria for screening. We could expect certain engineers who are not currently SE's (other engineers) to have the SE profile, in other words, the potential to perform SE tasks and activities. It is this group that would be aimed at development.

If we are able to define a SE profile, i.e. $\boldsymbol{H_1}$ is a valid hypothesis, then we need to validate the screening methodology. The resulting SE profile would be baselined and we can proceed to the validation of the screening methodology, discussed in the next session.

5.2. The Screening Validation Phase. In order to *validate* the screening methodology, we would have to show that the designed screening methodology predicts the development of SE potential. The validation phase would start by identifying and assessing *candidates* in DPSS (*candidates* are engineers who are not SE's with at least three years experience) via the psychological assessment measures (CPP, VO, 15FQ+) as well as the Systems Engineering Competencies Questionnaire. This would define a baseline. We would then apply the discriminant function, as developed during the screening design process. Our choice of sample means that generalising results beyond the DPSS may be difficult. However, this is not currently an objective of the study. In order to discriminate between normal learning on projects and the effects of the development effort (Figure 3) a control and a development group would be created, and the candidates would be randomly assigned to the two groups. The control group would do projects as usual. The development group, in addition to doing projects, would receive training, coaching and facilitated workgroup sessions (Gonçalves 2008) over a period of 2-5 years. The candidates would be assessed periodically over this period on the SE dimension (by completing the Systems Engineering Competencies Questionnaire), to assess whether their level of competency has increased. The candidates will not be assessed on the psychological assessment measures again, due to the fact that these attributes are expected to remain relatively stable. In addition, the candidates have already been classified as systems engineers or other engineers. The proposed assessment rate is yearly, based on the rate of development of candidates and business reporting cycles. Results of the study should indicate a difference in development between the control group and the development group, thus confirming $\boldsymbol{H_2}$.

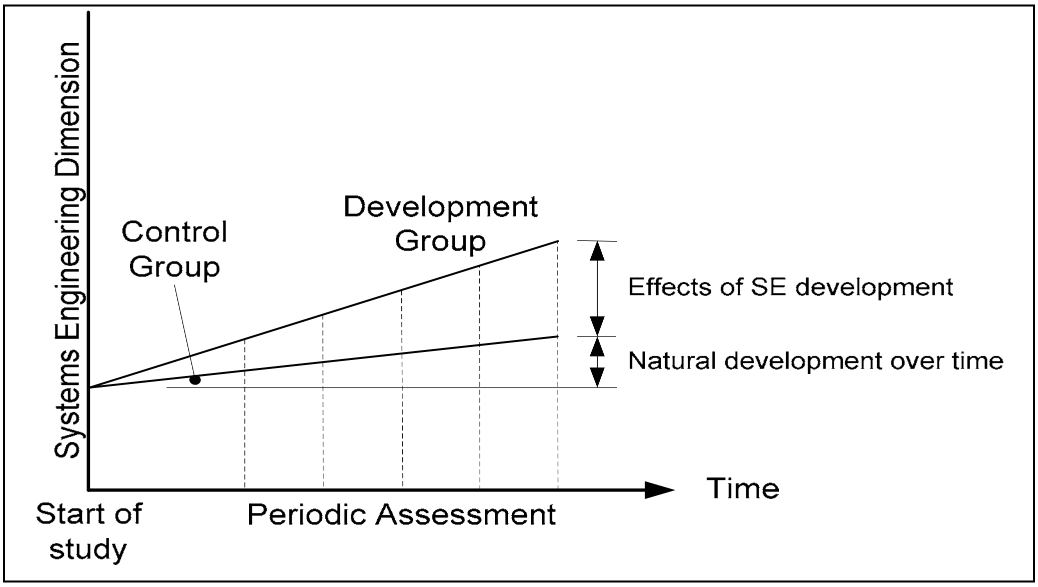

Figure 3. Separating natural vs. deliberate development using a control and development group

The two groups would consist of a mix of engineers with the SE profile and the OE profile and the demographics would be the same as in the screening design sample for the same reasons. We would expect candidates with the SE profile to show a higher increase in SE competency in contrast to candidates with the OE profile. From the results of this study, one should be able to successfully screen candidate engineers for development to become SE's at DPSS. We realize that our study has limitations, since the DPSS results cannot be generalized directly. However, our results could form a starting point/basis which others could build upon.

Our research proposal has received ethics approval. A small pilot study has been conducted to evaluate the assessment process and a number of improvements were made to the SE competencies questionnaire. We are currently assessing DPSS candidates as part of the screening design phase of the study.

Conclusions

In DPSS recruitment strategies alone are not sufficient in addressing the shortage of SE's, and SE training programmes are not always successful as some candidates do not show adequate development. This could be related to the fact that some candidates to not have sufficient potential to become systems engineers, in other words they don't have the SE profile. Previous research studies that have attempted to define the 'SE profile', do not seem to look at the assessment model in its totality – they identify a set of characteristics which, in some studies, may appear to be vague. Additionally, previous research does not seem to link these characteristics to *individual* SE competencies (such as requirements, modelling and simulation or speciality integration). A list of characteristics alone may not have much benefit to the organisation if these cannot be measured for screening, recruitment or development purposes.

We believe this study has the potential to identify measurable attributes relating to personality, cognition and values, taking into account the inter-relationship between these, that predict development of SE competencies. If this can be achieved, we can advance screening for SE potential to a point where it can be used practically. Our proposed use of values appears to be novel in this context. We expect that because the study is limited to DPSS we may not have sufficient data on all twenty one competencies, because of the nature of the work. The results might also not generalize to other organisations.

It is important to note here that the purpose of our screening methodology is not to limit opportunity for engineers to become Systems Engineers. On the contrary, it can help identify potential in younger, less experienced engineers for development. Also, we are not trying to define the profile of the perfect, but generic, systems engineer. Rather we are attempting to establish a framework of characteristics for different SE competencies which taps into a broader pool of engineers. By identifying this profile, we can allocate company resources more efficiently to candidates who show the most potential for the job. Additionally, we can identify potential sooner, and develop this potential more successfully.

By establishing a screen methodology, validating it, and then applying it to screen and develop potential SE's, not only will the shortage, but also the *quality* of systems engineers be addressed and improved. Identifying potential is invaluable, especially in South Africa, where gender and race transformation in the workplace is a goal.

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BIOGRAPHY

Duarte Gonçalves holds a B. Eng in Electronics and a M. Eng in Computer Engineering and is currently employed by the CSIR. He has been involved in engineering surveillance systems for the South African DoD where he has extensive experience in electro-optical systems, ranging from modelling the environment and electro-optical observation systems, to signal and image processing. He holds a full patent in the area of imaging spectrometers. He has consulted to the Karoo Array Telescope project, the South African technology demonstrator for the Square Kilometre Array (SKA) as a systems engineer. Mr. Gonçalves is currently responsible for developing systems engineering skills at the CSIR.

Janine Britz attained a BsocSci Psychology degree with distinction at the University of Pretoria in 2006, where she majored in Psychology, Criminology, Research and Philosophy. She completed her honours degree in BsocSci Psychology in 2008. She has also been a member of the Golden Key International Honour Society since 2004. Currently, she is employed by the CSIR as a research intern, where she is researching the psychological dimension in systems engineering, specifically by researching and collecting data on SE personality, cognition, behaviour and motivation. She has also been involved with research in cognitive engineering, specifically cognitive task analysis and cognitive work analysis in macro-cognition.