Understanding Requirements Engineering Process:
a Challenge for Practice and Education

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ABSTRACT

Reviews of the state of the professional practice in Requirements Engineering (RE) stress that the RE process is both complex and hard to describe, and suggest there is a significant difference between competent and "approved" practice. "Approved" practice is reflected by (in all likelihood, in fact, has its genesis in) RE education, so that the knowledge and skills taught to students do not match the knowledge and skills required and applied by competent practitioners.

A new understanding of the RE process has emerged from our recent study. RE is revealed as inherently creative, involving cycles of building and major reconstruction of the models developed, significantly different from the systematic and smoothly incremental process generally described in the literature. The process is better characterised as highly creative, opportunistic and insight driven.

This mismatch between approved and actual practice provides a challenge to RE education - RE requires insight and creativity as well as technical knowledge. Traditional learning models applied to RE focus, however, on notation and prescribed processes acquired through repetition. We argue that traditional learning models fail to support the learning required for RE and propose both a new model based on cognitive flexibility and a framework for RE education to support this model.

1. INTRODUCTION

Requirements Engineering (RE) is an early phase in systems development life cycle. RE is concerned with the determination, communication and specification of user requirements for the system to be developed. RE has often been widely recognised as a cognitive problem solving process, involving conscious mental efforts to come to a decision (see for example Batra and Davis, 1992). Over the last decade, many authors attempted to describe the structure of the RE process and what the requirements engineers (REers) do during this problem understanding and solving process. There is some variation, in the literature, in the descriptions of the RE process. Traditionally, the process is seen as hierarchically organised, with the decomposition of complexity into smaller, manageable units. Recently, opportunistic behaviours are observed to be critical in the RE (Guindon, 1990; Khushalani et al., 1994; Carroll and Swatman, 1999). However, the questions of how they occur, what their triggers are, and what their impact on the complexity of the problem and the requirements model is, have not been described adequately.

Moreover, reviews of the state of the professional practice in RE stress that the RE process is both complex and hard to describe, and suggest there is a significant difference between competent and "approved" practice. "Approved" practice is reflected by (in all likelihood, in fact, has its genesis in) RE education, so that the knowledge and skills taught to students do not match the knowledge and skills required and applied by competent practitioners.

This paper attempts to address this mismatch by describing a new understanding of the RE process and discussing its implications in RE education. The paper is structured as follows.

- Section 2 briefly discusses the RE process and describes a new understanding of the process.

- Section 3 discusses its implications in teaching and suggests a new learning framework for RE education to support the new understanding of the RE process. This section also briefly describes findings from a case study at a University in Australia adopting the new RE education framework.
- Section 4 concludes the paper.

2. HOW DOES THE RE PROCESS OCCUR?

2.1. "Approved" and competent practice?

There exist different descriptions of the RE process. There exists a dominant view (and expectation) that the RE process should be systematic, structured, evolutionary. Loucopoulos and Karakostas (1995) describe a very widely accepted RE cyclic process model with each cycle consisting of elicitation, analysis and validation activities. During this cyclic process, requirements are elicited, analysed, modelled, and validated. Therefore, requirements model will be refined and improved and gradually become an accepted specification of user requirements. Alexander (1998) acknowledges the collaboration between the users and the developers and sees the RE process as cyclic consisting of co-operative inquiry between these different stakeholders. The cyclic co-operative inquiry process consists of proposition, action, reaction and reflection – during this cyclic process, requirements tasks are proposed, debated; accepted tasks are performed; feedback is sought, and problems are refined to suggest further actions. Robertson and Robertson (1999) describe the RE process as a more sophisticated asynchronous network of activities which can be customised to specific applications.

Although the detailed descriptions of the RE process may vary from author to author, at a high level of abstraction, the requirements problem space is structured and refined in a generally cumulative mode. This dominant view tends to reflect the common agreement within the RE community about the RE process and its underlying engineering principles. Clearly, all these process models are good arguably attempts to structure and improve the RE process.

Interestingly, while this view seems to be "approved" process models in the literature and textbooks, Hofmann and Lehner (2001) examined 15 RE teams in industry revealed that a clear majority of competent practitioners consider RE as an *ad hoc process*, with only a minority of them using a defined RE process with different degree of modification. The authors observed that the RE practitioners "*struggle with the classic problem of rapidly fluctuating requirements*" which *requires "flexible requirements" that "can be clarified and changed as the product progresses*" Hofmann and Lehner (Hofmann and Lehner, 2001, p. 62). Even more interestingly, the authors suggest that the RE process should account for *stakeholders' learning curve* which takes place during the process. First, this is a clear indicator of a gap between what we think we know about the RE process and what really takes place when practitioners practice RE. Further, it leads to interesting questions – what is the learning curve like, and how does it happen?

2.2 In search for an understanding of the learning curve

In search for an understanding of the learning curve, another school of thought postulates the opportunistic nature of the RE process. Guindon (1989) describes the RE process as intensive knowledge discovery process. According to Guindon (1990), the ill-structuredness of the requirements problem is an important factor inducing the opportunistic behaviours of the designer. Later in Khushalani's (1994) study, the RE process is described as an unpredictable and adaptive exploration of problem areas, which is "characterised by frequent discovery and/or adaptation of goals and activities, in response to changing circumstances" (Khushalani et al., 1994, p. 13). Carroll and Swatman strongly suggest requirements engineer's traversal of the problem space is by no means orderly during the RE process. Through an action research study, Nguyen and her colleagues (1999) observe occasional major restructuring of and leading to significant simplification of the requirements model. According to these authors, the RE process is not smoothly evolutionary; the learning curve consists of a series of solutions to problems/sub-problems with critical solutions rather insight-driven than being derived through a systematic evaluation of alternatives.

A more recent action research study (Nguyen and Swatman, 2003) revealed the RE process as consisting of cycles of creative construction and insight-driven reconstruction of the problem space. This is described in the following section.

2.3 Catastrophe cyclic process model

At an overall examination level, the RE process was cognitive, involving continuous mental effort to understand the requirements problem and to make decisions to solve it. The process consists of frequent opportunistically guided episodes of a range of activities: acquiring and understanding information from problem domains and representing and validating it in the requirements model.

At a close examination, the RE process involves cycles of creative building up and major reconstruction of the requirements model, significantly different from the systematic and smoothly incremental process generally described in the literature. We characterise the pattern of construction and reconstruction of the requirements model through our catastrophe-cycle RE process model (see Figure 1).

Figure 1. The catastrophe-cycle RE process

This process can be described as follows:

- As the requirements are acquired, analysed, and added into the requirements model, the complexity of the model grew over time. The requirements engineer's learning of the requirements grows gradually as they explore further and further into the problem space and exchange their learning over time. In addition to analytical, people and communication skills, creativity plays a highly important role during this learning process. The requirements engineer continuously perceives and shapes the problem space in immediate organisational and business context within which the RE is exercised. Creativity is demonstrated through ways of seeking for further information, classifying and sorting information gathered, flexibly exploring and moving between different problem areas to gather, and analyse and model the requirements. The requirements engineer is actively engaged in learning about (or constructing of) the problem and solving it.
- At some unexpected crux point, the requirements model is significantly simplified and restructured. The problem space is reconceptualiased and the requirements model has a new architecture reflecting a change in the way the requirements problem is perceived by the requirements engineer. The critical points often happen as a result of a sudden, unexpected insight – similar to the "Aha!" moment, rather than through systematic and planned efforts.
- After this, the requirements model undergoes through the next cycle of creative structuring and rather opportunistic restructuring of the requirements problem.

Although the overall complexity of the model is reduced significantly at the crisis points, the requirements engineer's learning about the requirements *must* increase. The critical restructuring of the requirements model results in a better understanding of the requirements and solves a requirements modelling problem from a new perspective (often with a more holistic view); and the problem space is more elegantly structured. Therefore, the relationship between model complexity and level of understanding is <u>not</u> monotonic.

2.4 Discussion – RE creativity

The catastrophe cyclic RE process appears to be:

- in line with the intuition of the professional community
- in line with the literature in general problem solving, but
- in conflict with the commonly accepted view in the RE literature.

Firstly, the catastrophe cycle RE process resonates with the RE professional. Practitioners with whom we have discussed our work uniformly confirm that the real RE process is different from the "approved" smoothly balanced, incremental process. In his article about creativity in software development, McBreen points out that most design documentation "is written as if the design was developed linearly in a clean sequential manner", therefore we tend to assume that the "*creation process should be linear as well*" (McBreen, 1999) .

Secondly, the catastrophe-cycle process is in line with literature on problem solving, creativity, and general science. Indeed, the catastrophe cycles within the RE process is reminiscent – at a micro level – with Kunh's (1970) concepts of paradigm shifts between periods of so called "normal science".

The catastrophe cycle model can be compared to classical Wallas model of the creative problem solving process. Wallas (1926) identified four stages of invention: preparation, incubation, illumination (insight), and the verification and expression of insight. Later, Hadamard (1954) and Poincaré (1952) further developed this creative model through their explanation of conscious and subconscious layers of cognitive activities exercised by the problem solver. At the first stage, the consciousness works as preparatory by exploring the problem areas and shaping directions that the unconscious may follow. Incubation is often described as the period when the problem solver moves away from the problem in hope of reaching a solution. Illumination can be viewed as a breakthrough by unconscious ideas when consciousness is weakened. The instant insight is often referred to as a sudden creative thought associated with an "Aha" or the Eureka effect which solves the problem in a simple and elegant way. This invention process is consistent with the catastrophe cycle process that at crux point when the reconceptualisation insight occurs, the requirements model undergoes major restructuring.

In addition, the catastrophe cyclic RE process highlights two types of RE creativity – creativity associated with the structuring of the requirements model and insight resulting in the reconceptualisation and restructuring of the model. The first type or RE creativity can be related to the preparation and incubation phases in Wallas model. It can be associated with the dynamics of the essential complexity in the requirements model and is consistent with the description of the cognitive problem solving process offered by Gigch (2000). We define essential complexity in the requirements model as intrinsic understanding which is gained over time as the requirements engineer learns more about the requirements and transfers their learning into the model. Gigch (2000) suggests that in problem solving, the problem is processed through a number of cognitive functions. The problem is continuously interpreted and explained and the perceived complexity of the problem increases. At the reformulation points, the problem scope is expanded, and the complexity is gained at a higher level of abstraction and logic. This is consistent with our interpretation of the evolution of the essential complexity in the requirements model during the structuring of the requirements model.

The second type of RE creativity and its associated effect of major restructuring of the requirements model can also be related to Gestalt psychology of problem solving (Ohlsson, 1984). The Gestalt psychology school sees problem space restructuring as crucial in problem solving because it reveals a new way of conceptualising the problem. Restructuring is often associated with the occurrence of insight, a sudden, unpredictable flash of ideas which often involves a surprise and solves the problem in a rather simple way. In general design and architecture, Lawson (1997, p. 112) promotes creative thoughts and states that they are based on the *"idea of shifting the designer's attention and changing the context within which he perceives the problem."* RE insight, sadly however, has been somehow ignored in the RE literature. This is not to say that creativity and reconceptualisation insight do not occur in RE practice, they do inevitably. However they are not explicitly recognised and thus not adequately promoted in the dominant RE methods and techniques.

Finally, the catastrophe cycle RE process, however, is fundamentally different the commonly accepted view in the RE literature. Not only does the textbook literature describe the RE process as smoothly evolutionary and generally cumulative, but the research literature also focuses on a generally incremental model. For example, although the often cited description of the RE process by Pohl (1994) recognises different dimensions of the process, it still reflects a generally incremental, evolutionary process.

Undoubtedly, the understanding of the creativity and insight in the RE learning curve needs further examination and progress. Indeed, Maiden and Gizikis criticise the lack of studies in creativity in RE, review current research into creativity, and strongly argue for the recognition and need for creativity in future RE research. Recently, Maiden et al (2004) integrate the Wallas model (1926) within the RE process. In their approach, divergent thinking techniques are applied during the Preparation, Incubation and Illumination phases. Convergent thinking techniques are applied during the Illumination and Verification phases. The requirements model is revised after each Wallas cycle.

2.5 Implications – fostering and supporting creativity in RE

Although the catastrophe-cycle if viewed at a very high level of abstraction might look (smooth) incremental or have similar shape, the fundamental difference is the reconceptualisation in the requirements engineer's understanding of the client's requirements. It shows that the learning of the requirements is not simply the process of building knowledge by adding more information and details, but involving cycles of building up an understanding and reconceptualisation of that understanding at crisis points. Moreover, crisis points and reconceptualisation insight happen inevitably and need to be promoted, recognised and supported.

In practice:

- Deviation from the catastrophe cycle model would signal that the managerial actions may be required. The lack of shrinkage of the complexity in the requirements model would indicate the lack of reconceptualisation insight and cognitive flexibility by the requirements engineer while the excessive frequency of shrinkage of the complexity would indicate the lack of persistence in developing a mature understanding of the requirements problem by the requirements engineer.
- By ignoring the importance of crisis points, the current RE methods and CASE tools may hinder creative ideas and reconceptualisation insight. Indeed, McBreen states that linear, sequential models of software development *“drastically reduces our ability to create really great software”.*
- Although, it is not clear what triggers reconceptualisation insight, RE techniques and methods should promote cognitive flexibility and support the reconstruction of the requirements model when insight happens. New, effective approaches to monitoring and managing the RE process are clearly needed.

Current work is undertaken to examine RE creativity and relate it to various creative concepts and processes (Wallas, 1926; Csikszentmihalyi, 1997; Plsek, 1997; Torrance, 1997) to develop approaches and techniques to support RE creativity and insight. A new approach using design rationale has been suggested to fostering and supporting both the creative structuring and insight-driven restructuring of the requirements model when insight occurs. Interested readers are referred to read Nguyen and Swatman (2006) for detail about the current research work.

In education:

- The above deviation between ‘approved’ and actual behaviour is at the root of a major dilemma in RE education, and further exacerbates the challenge of educating REers. Introductory, tertiary level texts (which may be viewed as an embodiment of the current wisdom in the discipline) portray the RE process as smoothly incremental. These texts form the basis of RE education, and therefore propose, implicitly, a learning behaviour that models the accepted (as opposed to actual) behaviour of professional REers.
- The catastrophe cycle process strongly suggests that RE requires insight and creativity as well as technical knowledge. However, creativity is rarely or inadequately addressed in RE education (Dallman et al., 2005).
- This provides a new challenge in RE education: how can (and should) we train REers to work effectively in an environment, where insight and creativity are required.

The next section argues that traditional learning models fail to support the learning required for RE and proposes both a new model based on cognitive flexibility and a framework for RE education to support this model.

3. Towards a RE learning model

3.1. Traditional learning – how do we currently teaching RE?

The new understanding of the RE process described above provides a challenge for RE education. RE requires insight and creativity as well as technical knowledge. However, approaches to training REers based on traditional learning models tend to focus on technical knowledge, and are based largely on notations and prescribed processes. These differing perspectives have major influence on the underlying knowledge structures, skills (physical and cognitive) and techniques the RE has recourse to. Just as the creativity of this process is hampered by strict adherence to engineering and science methodologies, so too the education of its proponents is hampered by adherence to traditional learning models.

Accepting a smoothly incremental or evolutionary approach to the RE process equates well with traditional learning theories and models. In their simplest form these, based on behavioural theory, state that learning outcomes in a domain may be attained through the right set of instructional stimuli. Response to a stimulus is predictable and reliable – all the instructor requires is to identify the subskills to be mastered so that the intended behaviour is learned and to select the stimuli and strategy for its presentation that builds each subskill (Winn and Snyder, 1996). Amongst others, learning may be viewed as a progression to expertise through task analysis, strategy selection, try-out and repetition. These approaches are modelled in scientific and engineering methodologies, with their focus on process and repeatability.

However, the creativity of the RE process as revealed in Section 2 is hampered by strict adherence to engineering and science methodologies. These:

- restrict the essential characteristics of the process. Such as opportunism and insight-driven restructuring of the requirements model may not be understood and seen as undesirable changes/fluctuations of requirements essential gain of intrinsic understanding due to a new perception of the problem.
- assist in accidentally adding complexity through their attempts to control the RE's professional practice. Sutcliffe and Maiden (1992, p. 735) suggest strict adherence to method procedures may restrict natural problem-solving, and
- impose a plan at odds to the RE's cognitive planning mechanisms and hence interfering with the management of knowledge. Visser (1990) suggests in practice, a plan is followed only as it is cognitively cost-effective.

A poor fit between the characteristics of the domain and those of the learning model produce an ‘incorrect’ learning environment, where the learner is not directed to the important features of the domain. This is seen to impact greatly on the efficacy and efficiency of further learning (Gobet and Wood, 1999) and is especially relevant in light of the noted inadequacy of formal education in training competent analysts/designers (Robillard, 1999).

Attempts to deal with these issues have been made in the area of software design education, where the more traditional lecture + laboratory work + assessment tasks are augmented by either a capstone project which simulates a start to finish development environment or an industry-based placement (both typically towards the completion of the qualification). These are seen to provide opportunities for both authentic and experiential learning, with emphasis not so much on acquisition of knowledge as on increasing students' ability to perform tasks.

While accepted as valuable, this traditional approach is flawed in several respects:

- the opportunity (project or placement) is presented as an aid to content learning rather than a substitute
- it focuses on *know-how* which will allow students to gain competence to practice within given frameworks (but not necessarily outside of them)
- students are expected to transfer skills acquired to the world of work, but without them necessarily being rooted in cognitive content and professional judgement based on Savin-Baden’s learning Model II (2000). According to these authors learning for professional actions requires the gain of both practical and performative knowledge and focuses on real-life situations that require an effective practical solution.

Although providing experiential learning opportunities, learning from experience is not automatic: it requires transfer - the ability to apply something learned in one situation to another setting (Kearsley, 2000) - to be enabled. This transfer is enhanced where there is a focus on metacognitive strategies and reflection. It is this facet that is often missing from capstone projects and placements.

A new framework for effective RE education to address the poor fit between the current education approaches and practice and the creative RE process has been developed. It is described below.

3.2. A new framework for effective RE education

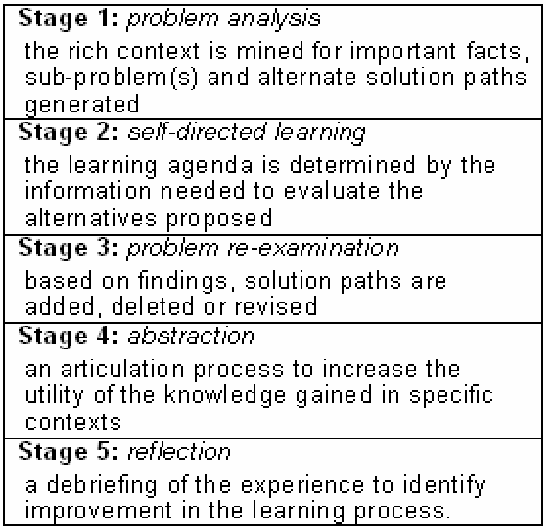
The characteristics of the RE process, as described Section 2, namely:

- its opportunistic behaviour,

- the need for model restructuring and problem reconceptualisation to deal with intrinsic complexity, and
- a dependence on insight and creative problem constructing and solving.

suggest that student REers require enhanced understanding of learning processes, including reflection and critical thinking in order to model the behaviour of practitioners. In order to enable these, the *Creative PBL* (Problem based learning) framework has been suggested. Table 1 describes five stages of Creative PBL and Figure 2 describes the Creative PBL process (Armarego, 2004).

Table 1 *Creative PBL* Stages (adapted from Koschmann et al., 1994)



Stage 1: *problem analysis* the rich context is mined for important facts, sub-problem(s) and alternate solution paths generated
Stage 2: *self-directed learning* the learning agenda is determined by the information needed to evaluate the alternatives proposed
Stage 3: *problem re-examination* based on findings, solution paths are added, deleted or revised
Stage 4: *abstraction* an articulation process to increase the utility of the knowledge gained in specific contexts
Stage 5: *reflection* a debriefing of the experience to identify improvement in the learning process.

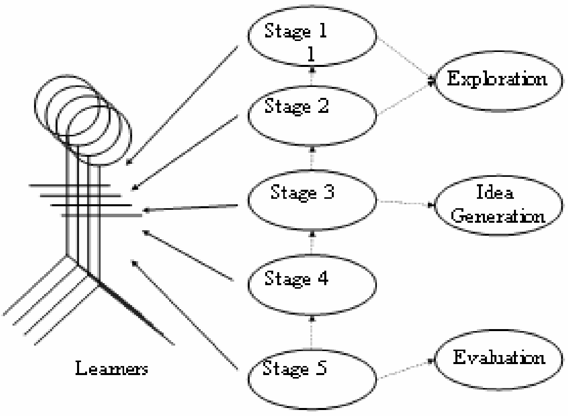


Figure 2. The *Creative-PBL* Process

The framework would meet the characteristics of the creative RE process and the challenges for education as described in sections 3.1 and 3.2 above through offering the following two features:

First, the create PBL framework has the following two theoretical foci:

- Focusing on developing cognitive flexibility and metacognitive learning strategies in student learning. Learning theories and models that focus on cognitive flexibility and exploit metacognitive learning strategies have greater potential for RE education. Cognitive flexibility includes the ability to represent knowledge from different conceptual and case perspectives and, later, the ability to construct from these a knowledge ensemble tailored to the needs of the understanding or problem-solving at hand the same items of knowledge need to be presented and learned in a variety of different ways and for a variety of different purposes. Metacognitive strategies include the development of cognitively flexible processing skills and the acquisition of knowledge structures that can support them. This theoretical focus of Creative PBL would develop the student's critical thinking and reflection skills to prepare themselves for opportunistic behaviours and cognitive flexibility required in problem structuring and restructuring.
- Focusing on the constructivist learning theory, based on three broad principles:
  - each person forms their own representation of knowledge
  - knowledge construction occurs when an inconsistency between current knowledge and experience occurs
  - knowledge construction occurs within a social context.

  The perspective that suggests that REers are not given problems, they construct (Visser, 1992) or discover (Guindon, 1989) them also suggests constructivist learning theory may address the challenge of educating REers. Knowledge construction and transfer are enhanced if there is a learning focus on strategic knowledge. This includes strategies for identifying and meeting sub-goals, procedural steps as well as metacognitive strategies for directing, monitoring and evaluating learning. In addition, learning models that address *wicked* domains (of which the above characteristics, as well as others, confirms RE as an example (Bubenko, 1995)) propose that a foundation in the content needs to be balanced with elements of creativity and experience based on practice.

The create PBL framework enable student to model the behaviours of practitioners through practising the art as well as science of RE

- be placed within a situated experiential environment where authentic context is exploited. Learning beyond the initial stages may best be achieved through situational case studies with rich contextual information (Dreyfus and Dreyfus, 1986). Focussing on the solution of authentic problems as a context for learning provides students with entry to the community of practice to which they will belong.
- provide the student with a *cognitive apprenticeship* (Berkenkotter and Huckin, 1995) with its emphasis on modelling practice and making tacit knowledge explicit. A cognitive apprenticeship allows the teacher to move from mentor to coach to facilitator as students are empowered to think independently.

More details about the Creative PBL framework can be found in (Armarego, 2004).

3.4 Empirical evaluation of the Creative PBL framework

An initial empirical evaluation of the Creative PBL framework has been conducted at an Australian University in 2004. Research subjects were students in a final year subject of a Software Engineering degree. Creative PBL was applied with the focus of the subject on divergent thinking and the development and evaluation of alternatives. The course material has been redeveloped for a PBL environment, and taught in this mode from February 2003. The Creative PBL environment took place in a (virtual) organisation *MurSoft*, collaboration between a software house and the university. Students were asked to work in teams, on short-term placement, on a project to develop gaming software. In their requirements engineering exercises, students were asked to explore and formulate the requirements problem they were given. This provided them with an authentic context for learning: students will have an opportunity to undertake an internship with a software-based organisation. It provides students with a process to deal with problems within a metacognitive-rich framework that makes complexity apparent and lets students deal with it adaptively.

A survey was conducted with the students who undertook the subject. Overall the feedback received indicated potential benefits and highlighted some lessons for further development of the framework:

- Students felt they learnt more in some certain the areas including self learning and motivation, communications (confidence to speak up, need to be heard and get ideas across) and team skills. Students felt easier to grasp concepts through project relevant components.
- There were different views on students' perception of the value of the new learning approach. Some students appreciated the authentic nature of the PBL environment while others students struggled and even felt lost, they required more structured guidance. This reflects a variety student preferred learning styles, for example deep approach to learning or surface learning. This issue deserves further investigation. More preparation is required in terms of learning styles and support structure in future development and application of the Creative PBL framework.
- While Creative PBL was believed to be a richer learning environment for the students, there is a need to track the student's progress throughout their degree and future career to evaluate the new education framework. Will they become more creative practitioners compared to previous graduates?

A more detailed analysis of the empirical evaluation can be found in Armarego (2004).

4. CONCLUSION

In summary, the paper points out the poor fit between “approved” and actual behaviour in RE practice. The poor fit is mirrored by a poor fit between learning models based on a behaviourist legacy. In an educational environment, this leads to an incorrect learning environment.

The paper describes a new understanding of the RE process and discusses the highly creative nature of the process. This new understanding of actual RE behaviour suggests that the metaphor of learning as dialogue should be exploited and suggests that a learning framework that acknowledges the place of cognitive apprenticeship better matched actual behaviour in RE. The creative PBL framework has been suggested based on a synthesis of learning theories and concepts including cognitive flexibility, metacognitive learning strategies, and constructivist learning principles. These concepts are integrated within an experiential learning environment to promote cognitive apprenticeship in the creative PBL framework.

In conclusion, this paper contributes to the current understandings of the RE process through highlighting the mismatch between “approved” RE process models and current RE practice, describing a new understanding of the creativity and opportunistic nature of the RE process, and discussing its implications in RE practice and particularly in RE education. The paper also contributes to the RE education practice by proposing a new PBL framework to the RE educators to address the above mentioned mismatch through supporting the creative RE process in RE education. The new framework will be further developed and evaluated.

To complete the paper, let us quote Robertson, a highly influential author in RE: “*We won’t make significant improvements to our software products by following a logical train of thought*” (Robertson, 2005, p.50). Robertson (2005) strongly argues that requirements engineers *must* also be inventors. Clearly, this is a challenge to RE practice as well as to education.

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