Software Engineering Research Strategy: Combining Experimental and Explorative Research (EER)

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Abstract. In this paper a new Experimental and Explorative Research (EER) research strategy is proposed. It combines experimental software engineering with exploratory research of new technologies. EER is based on several years experience of using and developing the approach in research of future mobile applications. In large international projects explorative application research includes quite often both industrial software developers and experienced researchers. This kind of an experimental research environment resolves the subject problem found in student experiments. It also does not have the difficulties found in experimental design and control of industrial projects that are constrained by strict commercial conditions. EER strategy provides benefits for both worlds: (1) experimental software engineering research benefits from almost industry level projects that can be used as experimentation environments, and (2) future mobile telecom application research benefits from better control and understanding of the characteristics of the applications and their development methods and processes.

1 Introduction

Software engineering discipline has struggled to become an established field of engineering and/or science. An experimental component is needed in software engineering for scientific validity (Basili 1996). However, there have been debates about the nature of the field and the research methodologies used. Traditionally software engineering has used very little experimentation (Tichy et al. 1995, Zelkowitz and Wallace 1998). According to these two extensive analyses of software engineering research publications, 50-60% of the published software engineering papers were not experimentally validated (Tichy 1998). This is a very high percentage compared to some other fields like optical engineering, where the percentage of invalidated papers is merely 15 %. On the other hand some prominent researchers advocate for less need of experimentation in software engineering (Hartmanis 1994).

Research and development of new technologies in fields like mobile applications is often exploratory and constructive. Proof of concept demos or prototypes are used to explore and push the limits of technology. The building of these prototypes is often an extensive project. However, the development is usually done using more or less ad-

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hoc process. The end-result is that, in a positive case, the project can only demonstrate the feasibility of the technology but not much more. There is no evidence of the effectiveness of the development methods for that particular technology development nor is there any convincing empirical evidence of the excellence of the technology itself. Therefore, there is a need to combine explorative research with empirical evidence, in specific in this research area.

In this article a new research strategy is proposed. In the strategy experimental software engineering is combined with exploratory research and development of new technologies especially in developing mobile applications for the future. The strategy is based on several years of experience in using and developing this approach in the research of future mobile applications. In large international research projects the research and development includes both industrial software developers and experienced researchers. This resolves the subject problem found in student experiments and alleviates the difficulties found in experiment design and control in industrial projects. The strategy provides benefits for both worlds: (1) experimental software engineering research benefits from almost industry level projects that can be used as experimentation environments, and (2) future mobile telecom application research benefits from better control and understanding of the characteristics of the applications and their development methods and processes.

In the following section a brief introduction of those aspects of experimental software engineering that are relevant for this paper is presented. In section 3 relevant research methodologies and paradigms for explorative research are discussed. In section 4 key issues of the research of future mobile applications are discussed. Mobile applications of the future form the application domain, where most of the experiences of the report were drawn. In section 5 experiences of combining explorative and experimental approaches in a research project are presented. In section 6 the findings and the proposed new research approach are concluded into a new explorative and experimental research (EER) paradigm. In the section also future research efforts are outlined. Due to the multidisciplinary nature of this paper the review of related research is embedded in each of the sections instead of a single review section.

2 Experimental Software Engineering

Experimental research in software engineering has gained popularity in recent years. Various experimental results have been published about experiments carried out both in vivo and in vitro (Basili 1996).

Table 1. Experimentation environment (Basili 1996).

In vivo	Experiment in the field under normal conditions
In vitro	Experiment in the laboratory under controlled conditions

The principle of an experiment is shown in Fig. 1. For example, if we study the effect of a new development method on the productivity we would define the

development method, tool support etc. as independent variables; productivity as dependent variable, treatment would be the use of the old and the new method, and the people that apply the method would be called subjects (Wohlin et al. 2000).

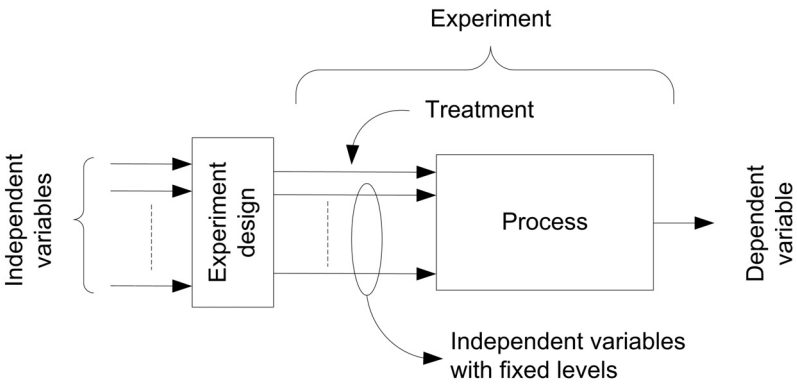

Fig. 1. Illustration of an experiment (Wohlin et al. 2000).

In an experiment we apply at least one treatment and control at least one independent variable. The focus of this paper is on experiments rather than other types of empirical research like surveys. Experiments can be categorized according to the number of teams replicating each project and the number of different projects to be analyzed in the experiment (Fig. 2).

Fig. 2. Experiments (Basili 1996)

		# Projects	
		One	***More than one***
# of Teams per Project	***One***	**Single Project**	**Multi-Project Variation**
	More than one	**Replicated Project**	**Blocked Subject-Project**

Observational studies do not include any treatments or controlled variables (Fig. 3).

Fig. 3. Observational studies (Basili 1996)

		Variable Scope	
		Defined a priori	*Not defined a priori*
# of Sites	***One***	**Case Study**	**Case Qualitative Study**
	More than one	**Field Study**	**Field Qualitative Study**

Traditionally experimental software engineering uses either students as subjects or organizes industrial experiments. Student experiments are problematic due to difficulties in scaling up the results into industrial software development. On the other hand, industrial experiments suffer from limited control of the settings of the experiment due to business constraints. Repeatability of the experiments is also problematic.

Validation method	Category	Description
Project monitoring	Observational	Collect development data
Case study	Observational	Monitor project in depth
Assertion	Observational	Use ad hoc validation techniques
Field study	Observational	Monitor multiple projects
Literature search	Historical	Examine previously published studies
Legacy	Historical	Examine data from completed projects
Lessons learned	Historical	Examine qualitative data from completed projects
Static analysis	Historical	Examine structure of developed product
Replicated	Controlled	Replicate one factor in laboratory setting
Synthetic	Controlled	Execute developed product in laboratory setting
Dynamic analysis	Controlled	Execute developed product for performance
Simulation	Controlled	Execute product with artificial data

Fig. 4. Experimental approaches (Zelkowitz and Wallace 1998).

Zelkowitz and Wallace (1998) define 12 experimental approaches (Fig. 4). The EER approach in this article covers mainly categories project monitoring, case study, field study (to certain extent), legacy, lessons learned, and replication.

3 Research Paradigms and Exploratory Research in Software Engineering, Information Systems and Other Domains

In this section a review of exploratory research is discussed in the context of software engineering and closely related information systems science. Some other scientific fields are also discussed in order to avoid re-inventing the wheel. The ideas of this section combined with experimental software engineering form the theoretical basis for the research strategy presented in this paper.

Exploratory research, which in our opinion is a required element in the research of future mobile applications, has not been recognized as mainstream research in either software engineering (SWE) or information systems (IS) research. Galliers (1992a, originally 1991) provides an excellent summary of alternative information systems research approaches listing the approaches as follows: laboratory experiments, field experiments, surveys, case studies, forecasting and futures research, simulation and game/role playing, subjective and argumentative, and action research. Järvinen (1999) provides a taxonomy consisting of: mathematical approaches, conceptual-analytical approaches, theory-testing approaches, theory-creating approaches, artifacts-building approaches and artifacts-evaluating approaches. Futures research certainly may be understood to be in the realm of exploratory research. Theory-building and artifacts-building/evaluating approaches likewise could be understood to be related to exploratory research. These approaches, however, do not grasp the gist of what is looked for in this article. Endres and Rombach (2003) in their excellent treatise of the empirical aspects of computing and the experimental approach to software engineering research do not refer to explorative aspects in research. They however note that although they have been emphasizing empirical and scientific methods in their book, they want to make it very clear that they do not want to lose the creative or

even artistic part of software and systems design. We see the same need in software engineering and information systems research.

Examinations of research undertaken during the past in IS field do not either reveal approaches that could be identified as exploratory. Hamilton and Ives (1992, originally 1982) analyzed strategies employed in 532 MIS articles published in 15 journals between 1970-79, Farhoomand (1992, originally 1987) in a similar manner performed a thematic analysis of research strategies of 536 articles published during the period 1977-85. While it is hard to say what is included under the term 'case study' in the two articles, any exploratory content seems to be minimal.

The need for exploratory research has however been noted for example by Banville and Landry (1992, originally 1989) who quote Herbert Simon in the following way: 'Science, like all creative activity, is exploration, gambling, and adventure. It does not lend itself very well to neat blueprints, detailed road maps, and central planning. Perhaps that's why it's fun.' From Hirschheim (1992, originally 1985) we can also pick Charles Peirce's notion that science should place as much emphasis on the processes of discovery as with how theories are justified.

The nature of future mobile applications necessitates therefore a look in other domains for a suitable research paradigm and strategy. We do not advocate the adoption of a paradigm based on exploratory research itself, rather the enhancement and combination of the empirical or experimental research with a strategy for finding or discovering the objects for research, which by definition do not exist yet.

Explorative research design is often proposed as the adopted research strategy when the problem is unclear, results are preliminary or tentative, and the research process is not defined or is in its early, formative stages. In many cases the references to the adopted research approach are from internal departmental working papers. Explorative research should not in our opinion be confused with theory-building approach or with case study approach (cf. e.g. Yin 1989). If a theory is sought and an explorative approach is chosen, the term theory-building suffices, likewise for case studies.

Explorative research has been quite widely used in social research. Govender (2003) used explorative research combined with descriptive research in studying adult distance learning citing Mouton and Marais (1990) as the theoretical source for exploratory research. According to Govender exploratory research aims to acquire new insights into a phenomenon rather than to collect and replicate data; to explicate central concepts; to determine priorities for further research and to develop new hypotheses about existing phenomenon. The research design of an exploratory study tends to be open and flexible.

Design research has also benefited from explorative research approach. Reymen (2001) used explorative research in her Ph.D. thesis and cited de Groot (1972) as the theoretical source. Reymen translated de Groot's approach as follows: "Explorative research is empirical research that is appropriate when the researcher is, on a relatively broad domain with little useful theory, confronted with an amount of observations or variables for which relatively few relevant facts are known. The researcher is, however, aiming at a certain type of relations, with corresponding ideas and relatively vague expectations. This aim determines which facts will be taken into account, what will be measured, and which kinds of relations will be studied. The goal of this kind of research is mainly not the ordering of facts or the creation of an overview of 'the existing', but it aims at establishing relations that are considered to be relevant for a certain theoretical or practical goal. The researcher starts from

certain expectations, from a more or less theoretical frame: He is trying to find relations in the material, but these are not defined by him in advance in the form of sharp hypotheses that can be tested; these hypotheses can thus also not yet be tested as such. Exact theory and/or hypothesis forming and testing must follow explorative research."

In marketing research whenever the focus of the research is the search for the dimensions of a question or the possible causes of facts it is referred to as "explorative". Explorative methods are mostly used to generate ideas and hypotheses and less to control assumptions. Explorative interviews stand out because the interviewer or presenter offers a wide range of possible answers thus concentrating more individually on the subject. (Skopos 2003). There are numerous examples of exploratory research also in various medicinal disciplines as well as natural sciences.

A little more rigorous approach is provided by Kleining and Witt in their two papers (Kleining and Witt, 2000 and 2001) mainly in the area of explorative psychology. The qualitative heuristic methodology applies four rules, which refer to the situation of the researcher, the topic of research, data collection and data analysis:

1. Openness of the research person
   - The researcher should be open to new concepts and change his/her preconceptions if the data are not in agreement with them
2. Openness of the research topic
   - The topic of research is preliminary and may change during the research process. It is only fully known after being successfully explored
3. Maximum variation of perspectives
   - Data should be collected under the paradigm of maximum structural variation of perspectives. There should be a multitude of different points of view, as different as possible: methods, respondents, data, time, situation, researchers etc.
4. Discovering similarities and integrating all data
   - The analysis directs itself toward discovery of similarities. It looks for correspondence similarities, accordance, analogies or homologies within these most varied sets of data and ends up discovering its pattern or structure. Completeness of analysis is required.

According to the authors the methodology has been used in social research and empirical humanities, e.g. in criminology, literature, popular music, theology, education, sick nursing and the study of national identities.

4 Exploratory Research on Mobile Applications

Research in future mobile telecom applications and services is often exploratory where prototypes and demonstrations of future applications are built in research projects, which are typically followed by demonstrations or field trial studies. These types of projects often include fairly large development projects but they often include more or less ad-hoc prototype development and they lack proper methods for understanding the development process and understanding the attributes of the new technology. In this section three research project examples will be outlined in order to

demonstrate the importance and role of exploratory part of our research strategy for the future technology development. They also demonstrate the historical evolution of the explorative ideas of research.

4.1 Virtual Prototyping Research

The roots of our exploratory research in mobile field date back to Virpi (Virtual Prototyping services for Electronics and Telecommunication Industries) project during 1996 to 1998 (Kerttula et al 1999). The research in the project was focused on shaping future product and service concepts in virtual reality design space, and advanced Virtual Reality based design environment was constructed. Besides physical appearance of products also product and environment functionality and behavioral modeling was studied. Virtual Prototyping environment allowed the project to create virtual prototypes of future telecommunication products and their associated services. Additionally, since the prototypes were virtual, the project was not bound to present-day technical limitations, but could take large conceptual and technological leaps into future product concepts. For example in the project it was possible to explore a pen-shaped cellular phone concept already 1998 although it has become possible to manufacture the electronics for such density only five years later.

4.2 Exploring Futuristic Media Phone Concept and Its Services Using Scenario-Based Design Approach

Since our research group was able to explore different product concepts in virtual design space, it became interesting to explore what a future cellular phone would be like and what might the new services be like. During the years from 1998 to 2000 an exploratory project called Cyphone (Cyphone 1998) was conducted, with a similar idea as car companies develop car design studies for their future products for automobile shows. In the Cyphone project it was assumed that future cell phones carry different multi-media formats and services and the focus was set on the concept of advanced media support. The project proposed a radical binocular shaped media phone concept and new services such as indoor and outdoor navigation and mobile tele-presence. In the Cyphone project a scenario-based design process was applied, where service ideas are first described with a storyboard, then expanded into a short multimedia movie with mock-ops, authoring and digital editing. The Cyphone movie was quite successful and has been presented hundreds of times to different audiences internationally.

4.3 Exploring Mobile Tele-presence Services

In the Paula project (from the year 1999 to 2001) (Paula 1999) mobile tele-presence services in the context of mobile virtual meetings were explored. In the project the research was focused on the design of interaction between the user and the service and explored what kind of user interfaces were best fitted for the new services. In the project the scenario-based design was applied into radically new, personal deviceless

user interfaces based on augmented reality. The interfaces were deviceless using an interface that was projected on user's hand.

5 Combining Exploratory and Experimental Research in Future Mobile Application Development Experiment

In this section a project example is presented, where exploratory and experimental research approaches were used, combined and feeding each other. The project, called Monica (www.monica.oulu.fi) was established in 1999 at the University of Oulu aiming to investigate topics on value-added service development for the 3G of mobile phones.

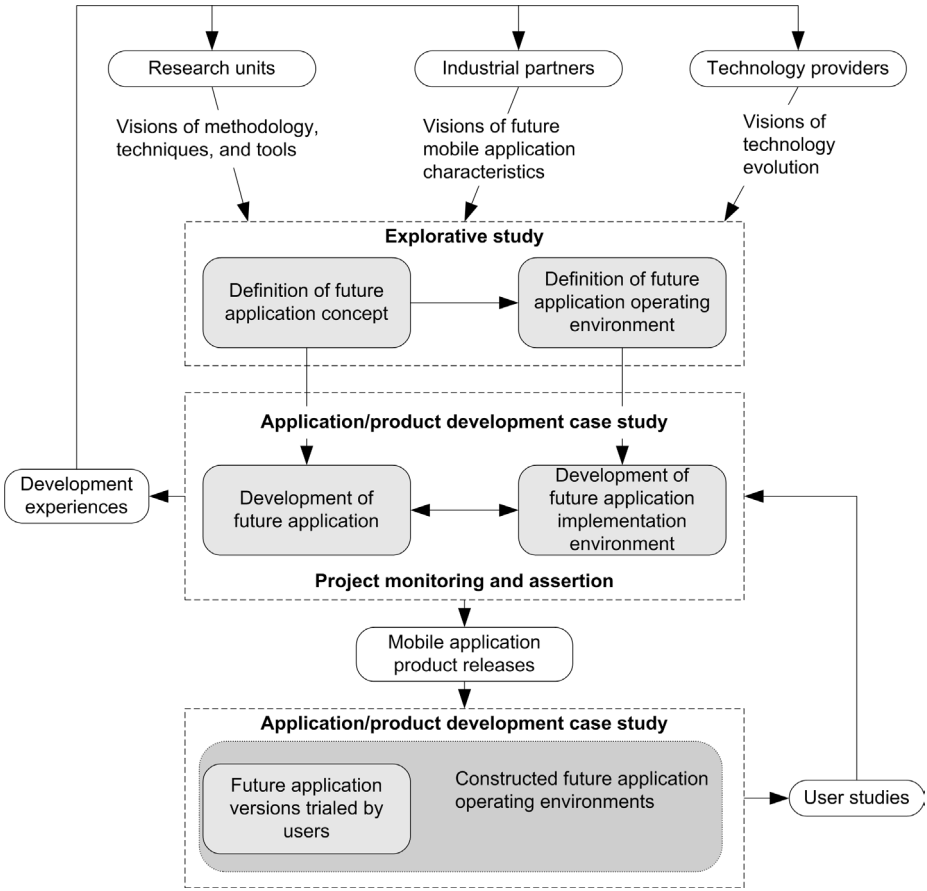

Fig. 5. MONICA research framework.

5.1 Research Context

The MONICA project was a challenging effort including industrial partners and research organizations aiming to experiment how the mobile applications might be developed in an efficient way in the near future. The time span to cover was 5 years ahead.

The entire research setting and roles of the participants are presented in the following figure (Figure 5). Industrial partners of the project represented both application development expertise (software house), technology providers (mobile telecom manufacturer), and application contents expertise (telecom provider). The visions of the features of the future applications were generated by the experts of mobile applications from the business point of view. The visions of the future technology were provided by the mobile telecom technology manufacturer. The visions of the future development approaches were defined by the software houses involved in the modern mobile telecom application business. The research organizations involved provided the insights of the exploratory and experimental research approaches and understanding of the new promising development approaches/technologies.

In Monica project both exploratory and experimental approaches were applied in parallel and communicating with each other. In parallel to the exploratory study the future application implementation was defined based on the visions from the technology providers. Based on that the future implementation environment was constructed by using current technological platforms and tools. In the following sections both exploratory and experimental development and research efforts will be presented separately in order to give insights of the efforts.

5.2 Exploratory Study on Product Concept Definition

The first step in the project was to define a vision for the product concept of the future application. The chosen case was a computerized version of *Arctic Bridge* (or *Tuppi* in Finnish), a traditional team-based card game that has its origins in Northern Finland. The game shares many similarities with bridge - its more widely known counterpart. The aim of this case was to construct a team game that would follow the idea of the original real world version. The rich interaction experiment was constructed in the form of 3D representation of the game, its players and the corresponding thematic environment. The game application was chosen as the application as it would push the limits of the mobile application especially to get as rich interaction as possible to get the game interesting.

The starting point of the work was to follow the traditional multimedia, game and film design processes from synopsis through media editing to programming. Although the system under development did not fit into the traditional multimedia or film context in terms of being purely presentational material, the basic process was considered to be close enough to start with. The overall research strategy was highly iterative and experimental. While the role of the application and technology development was exploratory. The main phases and the experimental context in the application development process are briefly described in the following (although the phases are here described in a certain order, this does not correspond to the realization of the work):

- *Synopsis* is the first written outline of the production and describes the most important aspects of the design. The approach and selected methods are decided at this stage. Rich interaction is visible as a design philosophy.
- *Background & Context Research* provides deep understanding of the background that informs better of the context and theme under development in the production.
- *Script Writing* is the main creative effort that produces the manuscript to be implemented.
- *Visualization and Concept Art* make the written descriptions visual.
- *Interaction Design* starts from the interactions illustrated by the manuscript and extends to the user interface. In a multi-player game, the interaction design is not just about human-computer interaction and physics models, but contains also issues such as interpersonal communication and group dynamics.
- *Level Design* includes designing the spaces and places for interaction, environmental cues and affordances for actions. This phase provides a more concrete illustration and plan of the virtual environment that forms the scene for the actions. The level design overlaps with the interaction design - the environment affords certain interactions and some interactions require specific features from the environment.
- *Materials, Models & Animation* is largely about modeling and animating the avatars.
- *Media Editing* contains fine-tuning the scenes, caricatures and facial expressions of the avatars.
- *Programming* is the part of the production that makes the story alive. Most of the functionality is set alive in this phase (e.g. animation sequences, physics model, control, etc.).
- *Integration* is the phase in which all the bits and pieces are put together, to work as a functional system. Combining graphics, audio, scripts, environment and models is an example of actions that need to be completed. In a way, this task is an ongoing activity starting from the first functional prototype until the final version is ready.

The industrial partners then evaluated the developed product concept and the application development could start.

5.3 Future Application Development – Project Monitoring and Case Study

The development experiment of the MONICA project consisted of a case study of implementation of a multi-client, multi-platform mobile card game. By analyzing similar systems developed by industrial companies (legacy research), it was evident that a special approach was needed in order to be able to support a large variety of client devices.

Most of the existing solutions were built around one platform and one bearer media. There were solutions for WAP over GSM link or Java applets over IP, or dedicated systems for connected Palm PDAs, and so on. This type of approach seemed to be the most robust and successful since it may leverage the strengths of one

single platform and eliminate the risks associated with combining different, incompatible technologies. A common characteristic of the analyzed solutions was the tight coupling between the business logic of the application and the presentation layer. These formed the specific features of the experiments.

The development experiment trailed applicability of agile development approaches for the development of future mobile applications. Research in the Monica project was performed in one-week cycles. During the weekly meetings experiences and feedback of the performed research and development were discussed and documented in meeting memos. In this way the research followed a quite normal agile software development process and could be combined for the demo and future application development cycles. Also the industrial partners participated in the weekly meetings occasionally and especially when their expertise was needed. This was project monitoring type experiment.

The experiment produced experiences of the future application concept development, future application implementation environment definition, and future application development approaches. The feedback was used as input to the experimental process as the experiment was performed in short cycles. One of the results of the experimentation was that a very productive method turned out to be the method, where there was a programmer making quick changes into the application product based on the feedback from a usability expert who watched the game being played. The programmer got immediate feedback and also quickly identified the problems. After changes the result of the improved application could be seen immediately. In this kind of situation, the changes to be made into the application will not become time consuming to conduct, and the results: "small releases" can be set for end-user evaluation rapidly. This was pair-programming between the usability expert and the programmer and provided an immediate alpha-test during the development cycles.

Integration of the ideas of XP (Beck 2000), and user-centered approach to software development was successful and provided good results. According to XP new versions of the product were delivered to the customers regularly (field study with real users at the Science Center[1]). The continuing dialog between the development team and the field study team was beneficial for both parties.

5.4 Observational Field Study on Mobile Application Product Usability

In the Monica project, the usability evaluation was a continuous activity throughout the design process. The developed releases of the future mobile application were implemented in the Science Centre Tietomaa for public use. The aim was to get the future application into use as early as possible, to find usability problems, to understand the reasons for the problems, and to give feedback and new ideas to programmers in order to assure that the development of new product releases will evolve into the right direction.

The main purpose of the field study was to ensure the usability of the user interface to guarantee satisfying playing experience. The main data collection method used was user-based observation complemented with individual interviews and questionnaires filled by the users. The user-based approach involved end-users interacting with the

[1] Science Centre Tietomaa, Oulu.

system and playing the card game. According to Parlangeli, Marchigiani & Bagnara (1999), in contrary to other methods, data coming from this kind of evaluation is directly derived from the subjects' experience. Many other techniques such as video recording of interaction, thinking aloud, and pre- and post-test interviews were used in the controlled environment in order to get measurements of relevant variables of the usability.

Also heuristic evaluation was used by including into the experiment card game experts, who inspected the system in order to find out possible problems in the user interface. This method, having the advantages of being cost-effective and comparatively quick and easy, was used many times during the development cycle.

Measures were set for the developed product including user satisfaction, predictability of the functions of the game, and fluent gaming experience. User observations, their immediate comments, and recorded feedback and also findings of heuristic evaluations, were written into the form of short stories, that was the way to present the research results in a way that supported the development of new releases of the card game product.

6 Exploratory Experimental Research Strategy

The new EER research strategy stems from the needs of empirical research in software engineering and explorative research in mobile applications research (Figure 6).

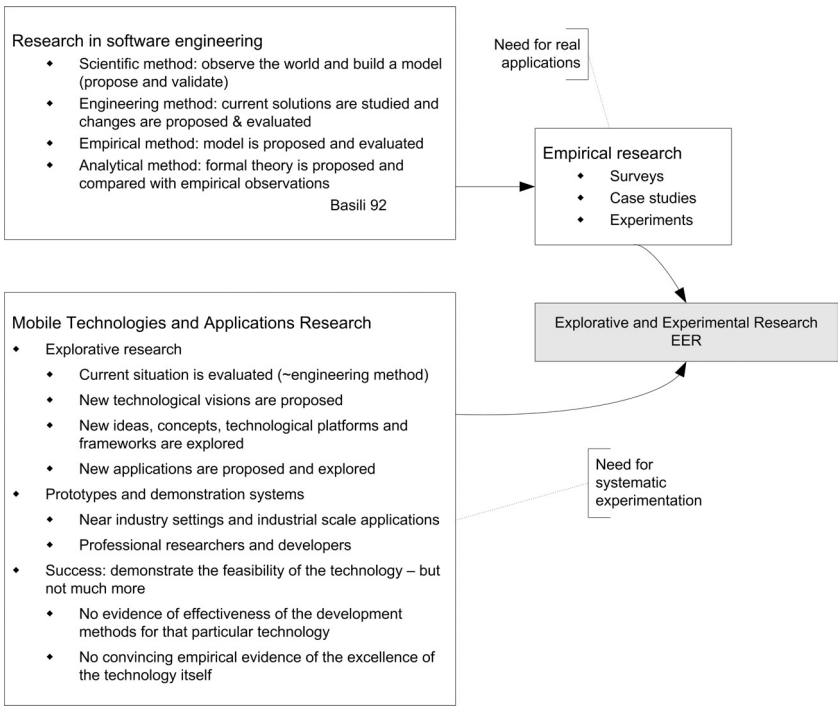

Fig. 6. Sources for Experimental and Explorative Research.

There is a constant need for realistic projects and applications when carrying out experimentation in software engineering. On the other hand there is a need (though often not recognized) for systematic experimentation in the research and development of future mobile technology and applications. By combining explorative and experimental approaches in the research and development of mobile applications we can provide help for both worlds. This is the core of the new explorative and experimental research (EER) strategy (Figure 7).

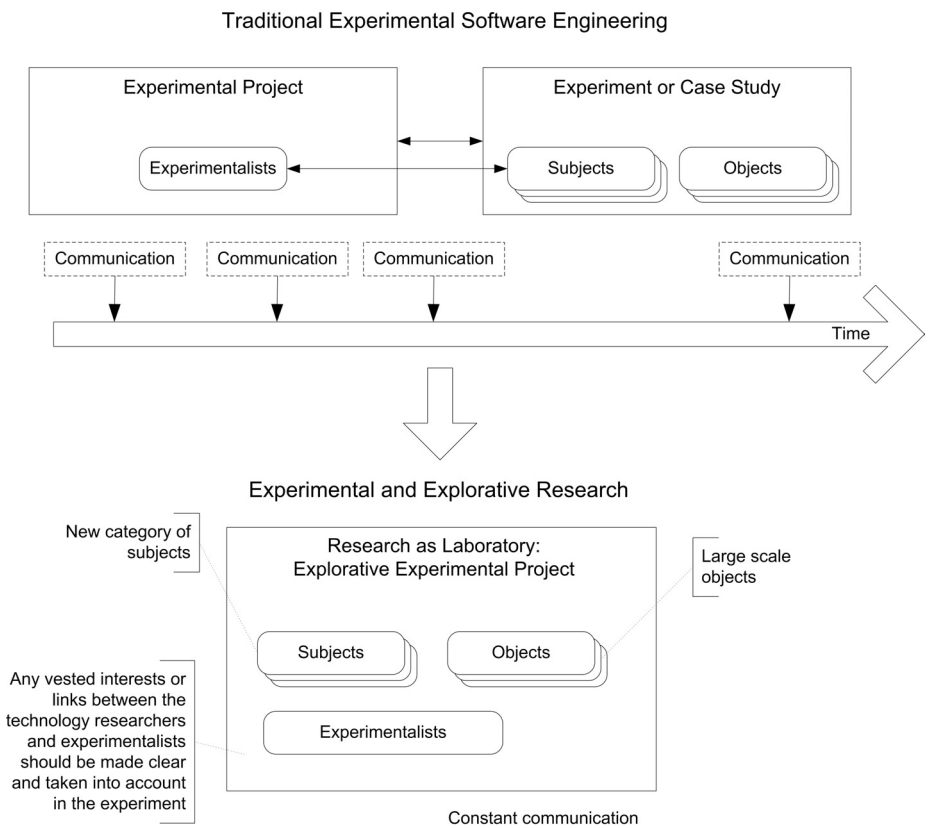

Fig. 7. EER principles and communication.

In traditional experimental software engineering (Figure 7, upper half) the experimentalists and the application developers (or the subjects) are separated. Their communication is pre-planned (points in time) and is, therefore, not natural. In EER (Figure 7, lower half) these two groups are integrated and based on that the communication is considerably improved. However, it is also important to take into account the risks of any vested interest when the groups are integrated so that the integrity of the experimentation is not jeopardized.

Explorative technology research is often iterative. Multiple versions of the prototypes are developed either based on previous versions or starting from scratch.

The nature of the research can benefit from replications of the experiment in different multiple iterations of the application development.

The experimental context is an industry like technology and application development. For data collection and analysis GQM approach is used (Basili & Rombach 1998). It provides proven methods for defining the object of study, the purpose, the focus and the point of view. The analysis follows the GQM method using both statistical techniques and human related techniques for qualitative analysis of the results in collaboration with the technology researchers and experimentalists. The collaboration of these two groups is essential to avoid false interpretations of the measurement results. Human interpretation of the results in addition to statistical analysis is essential (Latum et al. 1998).

7 Conclusions

A new research strategy that combines experimental software engineering and exploratory research has been presented. In an experimental exploratory research (EER) project a vision of the future applications and technology is first created. This vision may be visualized with various techniques including concept videos and virtual models. The vision is realized in a prototype in an experimental and exploratory research project. An experimental context is first designed to control, monitor, discover and learn while developing the prototypes in an exploratory development project. The exploratory prototype development is treated as an experiment and the developers are the subjects of the experiment. The objects of the experiment vary. They may be involved with development methods and processes or the underlying implementation technology.

EER is based on several research projects where the elements of the methodology have been used and developed. The main applications domain in these projects has been future mobile applications and technology.

The benefits of this strategy are twofold: (1) experimental software engineering research benefits from almost industry level projects that can be used as experimentation environments, and (2) future mobile telecom application research benefits from better control and understanding of the characteristics of the applications and their development methods and processes. The EER research makes a contribution to methodology research.

In practice both the explorative and experimental research included in a research project is performed in parallel, and their results are interactively “feeding” each other approaches. This is the way, how the results of the research project become combined as well as the conduct of the research approaches.

The research strategy proposed here will be used in new research projects concerning future mobile telecom technologies and embedded systems. The strategy itself will be also analysed more briefly in the light of scientific theories in order to confirm its explanation power.

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