REPORT

Technology Research Explained

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ABSTRACT

The purpose of this report is to contribute to a better understanding of technology research and the way to conduct it. The report pinpoints similarities and dissimilarities between classical research and technology research, and between technology research and action research. Hypotheses, predictions and their checking or testing are systematized and illustrated by examples. The report concludes that the three forms of research have similar characteristics and should be performed according to the same principal method.

The authors wish to inspire technology researchers to use this method more deliberately. It is our conviction that the method makes technology research more efficient. It reminds the researcher *what* to do, *when* to do it, and *why*.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Research	Forskning
GROUP 2	Technology research	Teknologiforskning
SELECTED BY AUTHOR		

CONTENTS

1 Introduction

1.1 Background

Research method is a relevant topic to anybody performing research of some kind, from basic research to applied, industrial research. There exists an abundance of literature prescribing how the researcher should work, what methods the researcher should use, etc. Explanations of research method typically take as starting point the kinds of research performed within the natural or social sciences, conveying guidelines to researchers of these disciplines.

What then about engineering? May the research method established within the classical sciences be adopted by ship designers, bridge constructors, computer scientists and other technologists? Or, is there an essential difference when it comes to approaches and problem formulation? By throwing light on these questions, the authors wish to contribute to a better understood and more commonly accepted research method for technologists.

1.2 Classical Research, Technology and Technology Research

The term *research* is defined in several different ways. According to Merriam-Webster [1], research is "investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws". Researchers formulate hypotheses and then check or test these by means of experiments and observations. Such testing is in the following referred to as *evaluation*. This approach is usually called *the scientific method* and is explained in a number of text books (e.g. [2]).

Honouring the ancient philosophers, scientists and their successors, we here use the notion *classical research method* about what is above called the scientific method. The term classical not only refers to the Greek and Roman cultures of the Antiquity, but also means "standard", "traditional" or "authoritative" [1]. Classical research is research focusing on the world around us, seeking new knowledge about nature, space, the human body, the society, etc. The researcher asks: *What is the real world like?*

Technology research takes another starting point. The word *technology* stems from the Greek word *techne*, meaning art, skill [1]. Technology may be defined as "the study, mastery and utilization of manufacturing methods and industrial arts" ([3]). Objects manufactured by human beings will in the following be called *artefacts*. The technology researcher tries to create artefacts which are better than those which already exist, e.g. quicker, more useful, or more dependable [4]. On this basis we define technology and technology research like this:

> *Technology* is "the knowledge of artefacts emphasizing their manufacturing".
> *Technology research* is "research for the purpose of producing new and better artefacts".

The technology researcher seeks principles and ideas for manufacturing of new and better artefacts, which may be materials, automates, medicines, oil production methods, computer programmes, etc. The basic question is: *How to produce a new/improved artefact?*

As we have now drawn the most important divide between classical research and technology research, it is relevant to ask how these two variants relate to basic research and to applied research. We make the following definitions:

Basic research is "research for the purpose of obtaining new knowledge".
Applied research is "research seeking solutions to practical problems".

While classical research is heavily rooted in basic research, technology research is more used within applied research (Figure 1). Note that some of the classical research is in fact applied (**A-C** in the figure); for instance, thermodynamics was invented in order to increase the effeciency of steam engines. On the other hand, technology research may also reside within the area of basic research (**B-T** in the figure). As an example, imagine a beautiful sculpture whose creation was made possible due to technology research on materials. Another example is Rubik's cube, a puzzle that reached high popularity among both children and adults in the 1980ies. In these examples, technology research is a means to create artefacts that do not solve practical problems, but which are beautiful or amusing.
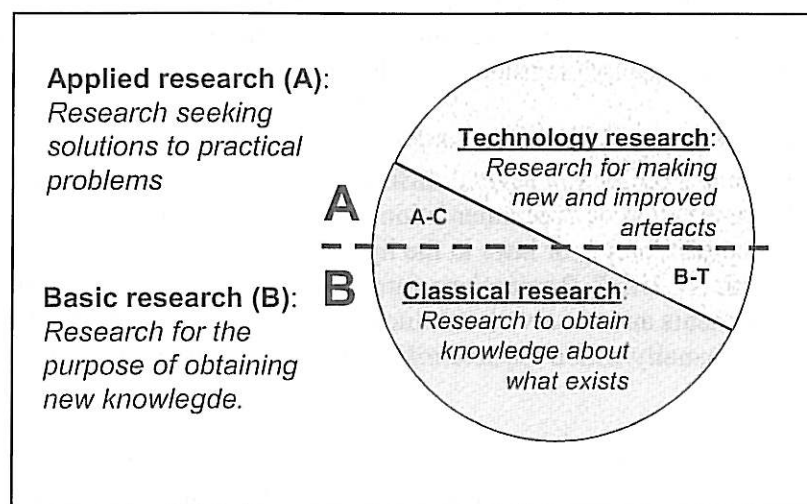

Applied research (A):
Research seeking solutions to practical problems

A

A-C

Technology research:
Research for making new and improved artefacts

B-T

Basic research (B): **B**
Research for the purpose of obtaining new knowlegde.

Classical research:
Research to obtain knowledge about what exists

Figure 1: Classical research and technology research are found both within basic research and applied research.

1.3 This Report

Chapter 1 has taken us through the purpose of the report and the definitions of some central terms. The next two chapters present the main elements of the classical research method (chapter 2) and the method for technology research (chapter 3). In chapter 4 we take a closer look at differences and similarities between these two principal methods. Chapter 5 gives a short introduction to action research and relates it to technology research. Chapter 6 is concerned with evaluation strategies in general, and chapter 7 gives examples of evaluation within technology research. Chapter 8 summarizes and concludes the report.

2   Classical Research Method

2.1 Goal: Knowledge about the Real World

Researchers in the classical sciences are occupied by theories about real-world phenomena. Having emerged from previous research, such theories may be either supported or challenged by researchers of today. In order to obtain legitimacy, a theory has to be supported by observations,

and it lives until it is refuted. An example of a refuted theory is Ptolemy's doctrine of the Earth as the centre of the universe[1] [5].

2.2 Hypotheses, Predictions and Evaluation

The starting point of a theory is the researcher's questions and his or her tentative explanations and answers. A tentative explanation is called a *hypothesis*. The researcher may have a set of alternative hypotheses. An essential part of the work is to find out whether the explanation agrees with reality. This is called *evaluation* (or *hypothesis testing/checking),* and is carried out by means of different types of *investigation (observation).* Evaluation is often based on *predictions,* which are statements about what will happen if the hypothesis is true. A prediction is on the form: *If H (the hypothesis) is true, then also P (the prediction) will be true.* Hence, observations showing that P is true, will confirm the hypothesis H. But observations showing that P is false, give cause for rejecting H.

Investigations may thus support (confirm, strengthen) a hypothesis, but cannot give an ultimate proof. On the other hand, would it be possible to find an ultimate proof to the contrary? That question leads us to discuss *falsifiability,* an important principle in hypothesis evaluation. A hypothesis is falsifiable if it is possible to reject (falsify) it through observations. Otherwise, the hypothesis is unfit for use within research. This principle implies that a hypothesis (or theory) that has been verified by many observations, still must be rejected if a counter-example exists. Karl Popper[2] was an advocate of falsifiability. According to Popper, evaluation should not attempt to verify a theory or hypothesis, but rather strive to falsify it. Only theories passing such tests should have the right to survive. Furthermore, Popper asserted that evaluation cannot give ultimate answers, and that hypotheses consequently always remain assumptions. Therefore, researchers should not try to avoid criticism, but accept that their hypotheses may be rejected [6][3]. The standpoints of Popper have been much referred and debated. One of the objections points to the possible situation of a sound hypothesis resting on a fallible theory. In such a case, the fallible theory would contribute to the formulation of erroneous predictions, which in turn would imply an incorrect rejection of the hypothesis [2][4].

2.3 A Classical Example

The physician Ignaz Semmelweiss lived in Austria-Hungary in the 19th century. His research on childbed fever makes a famous example of the classical research method. Semmelweiss was concerned about the large percentage of post-natal women dying of childbed fever in one particular maternity ward at the hospital where he worked. In this ward, it was Semmelwiss and his medical students who assisted the women. At the same hospital there was a second maternity ward which had a much lower mortality rate. The second ward was operated by midwives. After having rejected a number of possible explanations, Semmelweiss ended up with the following hypothesis: The childbed fever was caused by some material that his students, without knowing, carried on their hands from the autopsy room to the first maternity ward. He therefore instructed his students to wash their hands in a solution of chlorinated lime before entering the maternity ward. After this practice was introduced, the mortality rate in the first ward sank from more than 12 % to somewhat above 2 %, which was comparable to the mortality rate in the second maternity ward.

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[1] Claudius Ptolemy, geographer, astronomer and astrologer, lived probably in Alexandria about AD 90—168. His geocentric model had massive support among both Europeans and Arabs for more than a thousand years.
[2] Karl Popper, Austrian philosopher of science, 1902–1994
[3] pages 98–104
[4] pages 30–33

Semmelweiss' prediction was: If childbed fever is caused by an infectious material from the autopsy room, the women will not get ill if the birth assistants wash their hands with chlorinated lime in advance. This prediction turned out to be true, and the hypothesis of Semmelweiss[5] was confirmed.

2.4 Validity of Results

While hypotheses are general statements about a total population, or about all behaviours of a certain kind, predictions are made about some selected individuals, or behaviours. Therefore, it is important that results can be generalized; from the selected cases to all cases. Hence, both predictions and investigations have to be selected carefully. The investigations must be documented such that colleagues and others can evaluate the results. A researcher whose hypothesis is verified through observations, may plead new knowledge (new theory). In the opposite case, the researcher may start out again with other kinds of investigations, or even seek for another explanation.

2.5 An Iterative Process

When new theory is obtained, the researcher has a basis for new questions, leading to new hypotheses and investigations. Classical research is thus an iterative process.
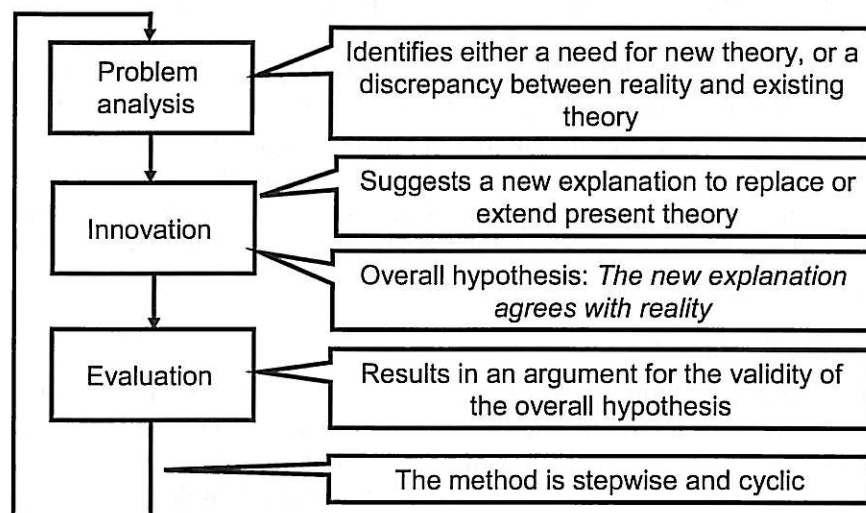

Figure 2: Classical research method – main steps

Figure 2 shows the main steps of this process:

1. *Problem analysis* – The researcher identifies a need for new or better theory. This need has arisen due to lack of theory, or because the researcher has found a deviation between present theory and the real world.

2. *Innovation* – This is the creative part of research. In this step, new questions are created, and good ideas are hatched. Sometimes, the innovation is moderate, but still useful, e.g. when existing theory is applied to another domain. Or, the innovation may be on the cutting edge, as

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[5] Another part of this story was the disapproval of Semmelweiss' explanation by the medical establishment at that time. Firstly, his hypothesis contradicted the current view of the causes of disease. Secondly, physicians refuted to have contributed to the death of post-natal women.

when Einstein elaborated his theory of relativity. The researcher works according to the overall hypothesis that the new explanation agrees with reality.

3. *Evaluation* – The researcher makes investigations to find out whether the new tentative explanation (the hypothesis) may be true. Taking the hypothesis as a basis, the researcher formulates predictions about the real world and then checks whether these predictions come true. If the observations agree with the predictions, the researcher can argue that the new explanation agrees with reality. Repeated confirmations of the hypothesis may cause its "promotion" to theory.

Sometimes, it turns out that observations reject rather than confirm the hypotheses. Far from being in vein, such investigations may also yield new knowledge, or encourage new iterations in the research cycle: problem analysis – innovation – evaluation.

3 Method for Technology Research

3.1 Goal: New and Better Artefacts

The technology researcher is concerned about how to make new artefacts or improve existing artefacts, e.g. a new robot, new algorithms for a computer programme, a new construction method for a bridge, a new medicine, a new treatment of patients, etc. The motivation is a need for a new artefact, or a need to improve an existing artefact.

The researcher starts out by collecting requirements to the artefact. For example, the artefact is required to tolerate a certain pressure, yield more dependable analysis results, manage a complex problem within a certain time limit, etc. Such requirements are stated by existing users (in case the artefact needs improvement) or by new or potential users (in case this type of artefact not yet exists). In addition, the researcher collects requirements and viewpoints from other stakeholders, such as those who are going to maintain the artefact or make money on it.

3.2 Hypotheses, Predictions and Evaluation

When the requirements have been collected, the researcher starts making an artefact which is supposed to satisfy the requirements. Despite the fact that nobody has done this before, the researcher assumes that it is feasible. The important question is how to go about it in practice. This phase is the innovative one, in which the researcher makes use of his or her creativity and technical insight. When the artefact is ready, the researcher has to show that it actually fulfils the posed requirements and thereby satisfies the (potential) need on which it is based. The overall hypothesis of the technology researcher is: *The artefact satisfies the need.*

In order to evaluate the overall hypothesis, the researcher has to formulate sub-hypotheses about the properties of the artefact, e.g.:

> H1: Artefact A is user-friendly.

However, neither such hypotheses can be tested straight away. Therefore, the researcher uses predictions, which are statements about the artefact's behaviour under certain circumstances. Predictions may be derived from the need and from the posed requirements. It is essential to formulate the predictions in such a way that they are falsifiable[6]. Let us take a look at the following predictions:

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[6] Refer to the discussion at the end of section 2.2.

P1: Artefact A can be used after a short training time.

P2: Artefact A can print 5000 word on paper during one minute.

P1 cannot be falsified straight away, because one first needs an agreement of what is "a short training time". On the other hand, it is much simpler to find out if P2 is false.

Predictions form the starting point of evaluation (hypothesis testing). To the researcher, evaluation may be just as challenging as the manufacturing of the artefact. Chapter 6 gives an overview of evaluation strategies.

Technology research does not always produce artefacts that are complete, regarded from a user's point of view. It is common to make a so-called functional prototype, which must be able to undergo the necessary evaluation. If the prototype looks promising, it can later on be elaborated to a complete, saleable product. Such finalization is typically done by other people than researchers.

3.3 An Iterative Process

If evaluation was successful, the researcher may argue that the artefact satisfies the need. The researcher has then made probable that the new artefact is useful, or that it is better than its predecessor. However, if the evaluation results diverge, the researcher has to adjust the requirements, and possibly build a new artefact and evaluate this one. Technology research is thus an iterative process, just like classical research.

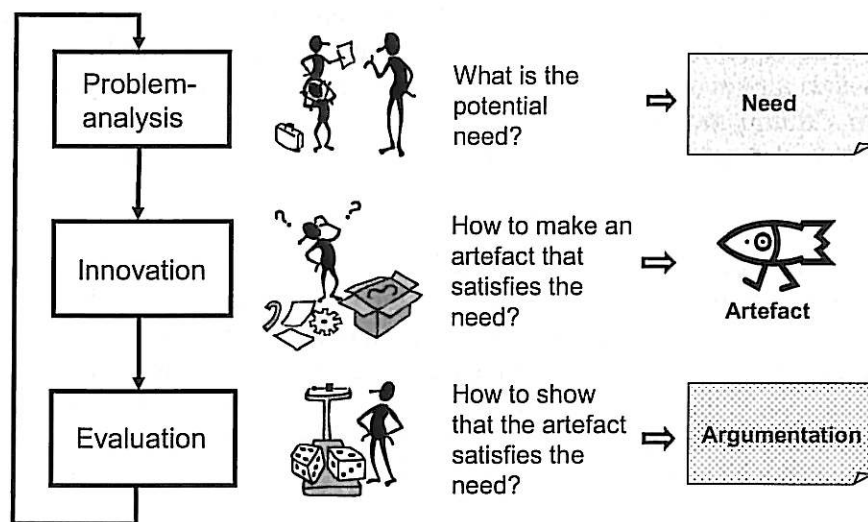**Figure 3: Method for technology research – main steps**

Figure 3 shows the main steps of this process:

1. *Problem analysis* – The researcher maps a potential need for a new or improved artefact by interacting with possible users and other stakeholders.

2. *Innovation* – The researcher tries to construct an artefact that satisfies the potential need. The overall hypothesis is that the artefact satisfies this need.

3. *Evaluation* – Based on the potential need, the researcher formulates predictions about the artefact and checks whether these predictions come true. If the results are positive, the researcher may argue that the artefact satisfies the need.

Just like in classical research, positive evaluation results confirm the hypothesis, but they do not *prove* anything. Negative or dissatisfactory evaluation results certainly impair the hypothesis, but nevertheless stimulate new iterations in the research cycle: problem analysis – innovation – evaluation.

3.4 Comparing Technology Development to Technology Research

Research and development are mentioned in the same breath so often that they form a term, even an abbreviation (R&D). This is with good reason, because research and development are closely related within the technology domain. On the one hand, a research project will typically include some development, and on the other hand, a development project may involve a research part. Due to its similar nature, technology development can preferably be carried out according to the same method as technology research.

What distinguishes technology research from technology development is the artefact's representation of *new knowledge* of some general interest. In order to decide whether an activity is technology research or technology development, we need to answer the following three questions:

1. Does the artefact represent new knowledge?
2. Is this new knowledge of interest to others?
3. Are the results and the new knowledge documented in a way that enables re-examination?

Let us consider an example: A large company needs to rebuild its computerized system for materiel procurement. It turns out that no standardized system is able to satisfy the need of the users in this company. Neither do other companies of similar type (and known by "our" company) possess a similar system. Therefore, it is necessary to build important parts of the procurement system from scratch. The company's IT professionals co-operate with colleagues in order to specify the system to be made. After several cycles of programming, testing and new requirements, the system is ready for use. It turns out that the majority of users are satisfied with the result, because they have got simpler work routines, better overview of the procurements, and more time to spend on tasks which were formerly put aside.

In the above example, the result was a success in that the artefact, the new procurement system, satisfied the need which was disclosed in the company. Let us now try to answer the three questions which were asked initially:

1. *Does the artefact represent new knowledge?* As far as we know, the new procurement system may be unique in the meaning "one of a kind". That is, however, not important. The essential questions are (a) whether any of the properties of this system (e.g. design, architecture) represents new insight, and (b) if this insight may become important for others who are to make similar systems. At this the next question is introduced, that of relevance.

2. *Is this new knowledge of interest to others?* The new procurement system as such may have no interest beyond the company that owns it. All the same, the system or some of its components may build on principles that are new and transferable to other settings. In that case, one can argue that the new knowledge is relevant.

3. *Are the results and the new knowledge documented in a way that enables re-examination?* Success stories need documentation in order to be trustworthy. Research requires documentation; the work shall be so well described that others may repeat and verify it.

Any issue in the position of spreading doubt about the knowledge and the results must be accounted for and discussed.

Results satisfying the three criteria above represent research and should as such be published. The purpose of publication is to make the results known among other researchers and among the general public. In this way, the results can be debated and criticized, and probably contribute to further research and/or development. Research dissemination is therefore of great importance to the research community and to the society at large.

4 Comparing Classical Research to Technology Research

4.1 What is "the Real World"?

We have distinguished between research on "the real world" and research directed towards the creation of artefacts – objects manufactured by human beings. A timely question then is: What is the real world? Most people will probably assert that the real world comprises a number of human-created objects. However, when talking about technology research we are interested in the creation of *new* artefacts; whether they exist only as ideas in the researcher's head, or they reside on the drawing board, or they are about to be manufactured. On the other hand, *old* artefacts are those which are already established in our (or the researcher's) environment. We count old artefacts as belonging to the real world, and research on these is performed according to the classical research method.

4.2 Testing Artefacts on Living Beings

Undoubtedly, living beings belong to the real world and cannot be called artefacts in our sense. But how to classify research which is supposed to create a new artefact, but which depends on living beings for evaluation? An example: Let us imagine the development of a new medicine which is supposed to fulfil the following requirements:

* The medicine shall be more effective than other medicines for the same illness.
* The medicine shall give fewer side effects than comparable medicines.

These requirements are concretized and transformed into a more detailed recipe for the new medicine. After some time, the new medicine is tried on volunteers, and their reactions to the medicine are carefully registered[7]. What is tested in this case is thus *the impact of a new artefact on the real world,* i.e., on humans with a certain illness. The result of the test is compared to the need that formed the starting point: Is the new medicine more effective, and does it give fewer side effects? Thus, we conclude that this is technology research, even when humans or other living beings are used in the evaluation.

4.3 The Motive of the Researcher, and that of the Stakeholder

As we have seen, classical science is driven forward by the need for new knowledge about the real world. Within technology research, the picture is different. The driving force for the technology researcher is the idea of the good properties of the new artefact. This artefact is supposed to satisfy a need for greater efficiency, better profitability, more beauty, or similar. The inherent challenge of achieving this goal is what triggers the effort of the technology researcher. However, the researcher is usually not the owner of the need to be satisfied. That need is owned by a

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[7] We assume that the researcher measures the results in a proper way in order to avoid bias. Within medicine, it is common practice to use double-blind experiments with control groups. This strategy implies that neither the patient nor his/her physician knows whether the remedy given is actually a medicine or a non-effective substitution.

(potential) stakeholder, being it an organization (e.g. a company), a group of persons (e.g. disabled people), or some other community or single person. The difference between the motive of the technology researcher and that of the stakeholder is as follows:

- *The researcher* is interested in inventing, or improving, an artefact that possibly may relieve the problem of the stakeholder.
- *The stakeholder* is interested in fulfilling a need, e.g. for improving the stakeholder's enterprise or activity, or for making it more efficient.

This apparent divergence need not represent any conflict between the two parties. On the contrary, it is assumed that the researcher's view and the stakeholder's view contribute to a common goal: a new or improved artefact that benefits the stakeholder.

4.4 A Unified View

So far we have focused on the differences between classical research and technology research. However, Figure 2 and Figure 3 suggest that classical research and technology research follow a common pattern. The table below emphasizes this pattern by comparing the main elements of classical research with the main elements of technology research.

Table 1: The main elements of classical research and of technology research

	Classical Research	*Technology Research*
Problem	Need for new theory	Need for new artefact
Solution	New explanations (new theory)	New artefact
Solution should be compared to ...	Relevant part of the real world	Relevant need
Overall hypothesis	The new explanations agree with reality	The new artefact satisfies the need

The starting point of either variant is a need. In the classical variant there is a need for a new theory, while in the technology variant there is a need for a new artefact. The solution sought in classical research is new explanations qualifying for new theory. The solution sought in technology research is the new (or improved) artefact. To check whether the solution comes up to expectations, one has to compare it to something:

- In the classical variant, one invents new explanations and compares these to a relevant part of the real world. The overall hypothesis is that the new explanations agree with reality.
- In the technology variant, one invents a new artefact and compares it to the potential need. The overall hypothesis is that the new artefact satisfies the need.

In both variants, the overall hypothesis is on the form "B solves the problem A". A is the need for new theory, or the need for a new artefact. B is a new explanation, or a new artefact, which satisfies the identified need. We have already mentioned that hypotheses are evaluated by means of predictions. How to evaluate predictions is the subject of chapter 6.

5 Action Research

5.1 Introduction

In the literature, action research is described as research and/or development directed towards the improvement of processes or systems within organizations. The goal is to reduce or eliminate organizational problems by improving the organization. The action researcher brings change into the organization by intervening it and then observing the effects of the changes. Action research differs from other kinds of research in that *the researcher and the researcher's activities are included in the research object*. In other words, the researcher and the object under study are not clearly separated.

Action research originated within social psychology in the middle of the twentieth century (see for instance [7], [8]). Later on, it has been used mainly within social research and medicine. As time went by, several variants of action research developed. Some of these are action learning, participative observation, and clinical field work [9]. Action research has been criticized for producing much action and little research [10]. Even though "action research" refers to the term "research", many of its activities come close to development, and the work of action researchers often borders on consultancy. Therefore, action research is not necessarily research in the sense that we have defined it (section 3.4). Action research may rightly be called research only when it provides new knowledge which is of interest to others, and which is documented in a way that enables re-examination.

In the following, we shall go through action research as defined by Davison et al. [11] and Baskerville et al. [9] and eventually examine the relation between action research and technology research.

5.2 Goal: Improved Organization

In action research, the aim is to solve a practical problem of a social/organizational kind by introducing changes. This way, the participants will obtain new knowledge about the situation as well as the change processes and the results. The action researcher builds on the presupposition that those who want to get new insight in the organisation have to study it as a whole. It is useless to parse the organization into components and consider e.g. the information systems as one separate part.

It is important for the participants to have a common understanding of what is going to be done, and to be aware of the advantages and disadvantages for the organization in which the method will be used. The co-operation should therefore be stated in a written agreement. Beside containing the client's consent, the agreement should, inter alia, make clear what is the interest of the researcher, and what is the interest of the client, in the work to be done.

5.3 Hypotheses and Predictions

Firstly, the action researcher and the client need to obtain a common understanding of the problem they want to solve. Secondly, they need to agree on which actions are appropriate for obtaining the desired improvement in the organization. The overall hypothesis within action research is: *Action A implies that the organization's need for improvement is satisfied.* A may be a single action or a series of actions. From this hypothesis one may derive several detailed hypotheses, such as:

> H1: Action A will imply that the employee staff becomes more stable.

A possible prediction of this hypothesis is:

P1: Next year, there will be a 50 % reduction in the number of employees leaving their positions in order to join other enterprises.

The predictions within action research is usually on the form: *In situation S and under circumstances F, G and H, the actions A, B, and C are expected to result in X, Y and Z.* According to Davison et al. [11], such predictions form the theory in canonical action research, as opposed to action *learning,* which lacks theory.

5.4 Evaluation through Collaboration and Learning

The predictions need to be evaluated within the organization. Since the action researcher takes part in the planned actions together with the employees and other involved persons, the researcher becomes part of his/her own research object. This kind of part-taking represents a challenge well worth considering.

The actions may certainly affect the individuals of the organization, e.g. change their roles and responsibilities, or require the employees to develop new skills. The structures and systems of the organization may be altered as well. Therefore, a thorough assessment should be carried out before the situation is altered, and also after the change has been completed.

The action researcher and the persons involved have to go through the results systematically and critically in order to find out what they have learned. The first question to ask is whether the actions performed did have the desired effect. If yes, it is necessary to find out if the original problem has been solved. If it turns out that the problem has been solved, they have to find out if the solution was brought about by the performed actions or was due to other causes. Another kind of learning considers action research as a framework; to what degree it proved useful to this type of problem, and in which way it should be adjusted according to this particular experience.

5.5 An Iterative Process

If it turns out that the actions did have the desired effect upon the organisation, then the action researcher is content. On the other hand, if the organization did *not* obtain the desired improvement, the practise should be examined. A new action plan may be necessary, and possibly also a reformulation of the original problem. Hence, action research is an iterative process, just like classical research and technology research are.
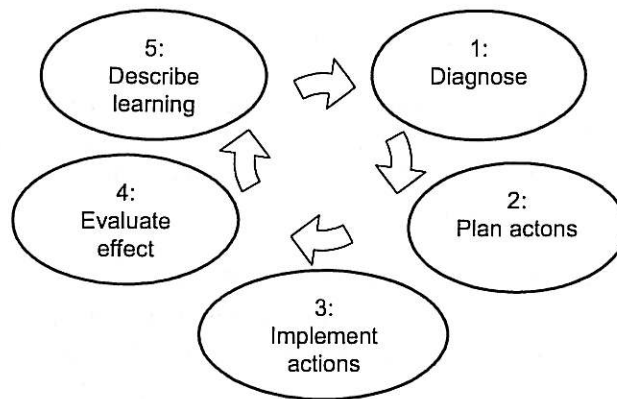
Figure 4: The five phases of action research (after [9])

Figure 4 shows the five phases of action research, being [9]:

1. *Diagnose* – identify the main problems underlying the organization's desire of improvement. The result is a description of the need and problem area of the organization.
2. *Plan actions* – in order to solve/remedy the main problems. This planning is performed by the action researcher and the organization's employees (the *practitioners)* in collaboration.
3. *Implement actions* – in order to obtain the desired change. The practitioners and the action researcher collaborate about active intervention in order to change the organization's processes.
4. *Evaluate effect* – regardless of it being negative or positive. The practitioners and the action researcher assesses whether the actions gave the desired effect, and if so, whether this effect really solved the problems. On the contrary, it becomes necessary to examine the course, and possibly also the hypothesis.
5. *Describe learning* – for three groups of stakeholders: the organization itself, the action researches involved, and the international research community.

5.6 What is Special about Action Research?

At first glance, technology research may seem to be something completely different from technology research and classical research. However, taking a closer look at the five phases of action research, we notice that they fit rather well into the pattern we already have. Figure 5 shows a possible alignment:

- *Diagnose* corresponds to *Problem analysis.*
- *Plan actions* corresponds to *Innovation.*
- *Perform actions, Evaluate effect* and *Describe learning* together make *Evaluation.*
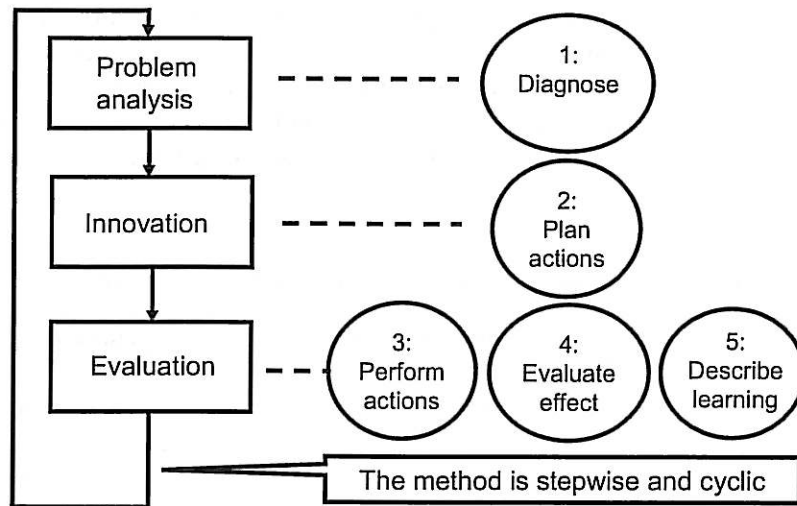
Figure 5: The five phases of action research (to the right) compared to the three main phases of classical research and technology research (to the left).

Figure 6 depicts action research in the three phases we already know. The problem analysis identifies the need for improvement in the organization, resulting in a description of this need. The innovation phase results in an action plan. The evaluation results in an argument for the validity of the overall hypothesis, which is that the actions imply the desired improvement in the organization.
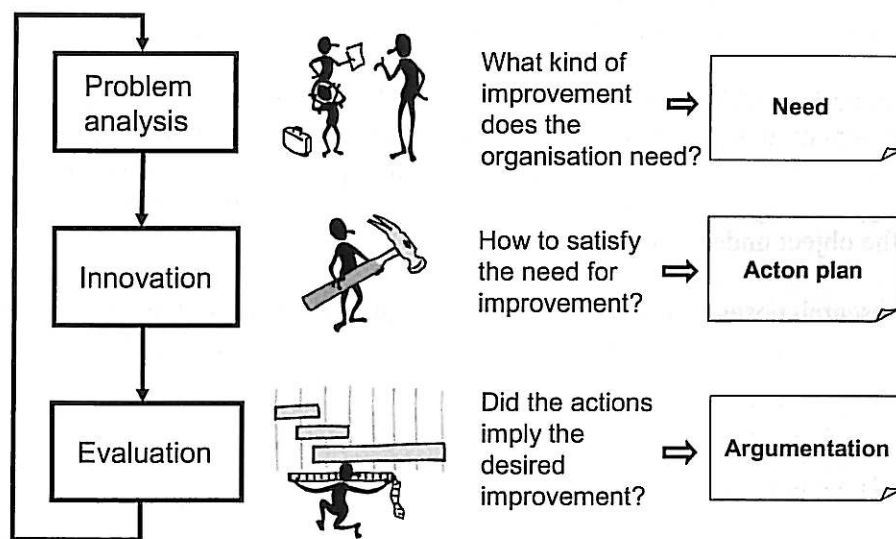

Figure 6: Action research in three phases

5.7 Comparing Action Research to Technology Research

As we have now seen how action research aligns with the pattern of technology research, a natural question is what these two research methods in fact have in common. Are they basically the same thing, or is the one a special case of the other? Table 2 compares the main elements of technology

research with the main elements of canonical action research. The starting point of either is a need. In technology research, the need is a new artefact, while action research addresses an improvement need in an organization. The solution in technology research is a new artefact satisfying the need. In action research, the solution is an improved organization that satisfies the need. We notice that, in both variants, the overall hypothesis is on the form "B solves the problem A". B is either a new artefact, or an improved organization, satisfying the need that has been identified.

Table 2: The main elements of technology research and of (canonical) action research

	Technology Research	*Action Research*
Problem	Need for new artefact	Need for improved organization
Solution	New artefact	Action plan
Solution should be compared to ...	Relevant need	Relevant improvement need
Overall hypothesis	The new artefact satisfies the need	The actions result in an improved organization satisfying the need

The action plan, which represents the solution within action research, often aims at introducing or changing a production method, an accounting system, a customer relations system, the personnel management, the organization chart or anything else influencing the organization's efficiency, profitability or similar. The intention is to improve the organization. To achieve this goal, the action researcher first intervenes with the organization's doings by e.g. introducing a new method, and afterwards examines both his/her own behaviour and the effects of it.

As mentioned in section 4.3, an organization is a human-made object, being itself an artefact. Development of an organization may hence be regarded as technology development. From that point of view, action research may be considered a special case of technology research (or of technology development). The difference lies in the fact that the action researcher is included as a part of the object under study.

Action research poses restrictions on the choice of evaluation strategies. Chapter 6 is about evaluation in general, and section 7.4 gives special account to evaluations strategies within action research.

6 Evaluation

6.1 Evaluation Strategies

As mentioned earlier, evaluation is to find out if the predictions are true. There are different ways to do this, regardless of the object of study being a new artefact or a part of the real world. According to McGrath [12], the most common strategies are:

- laboratory experiment – giving the researcher a large degree of control and the possibility to isolate the variables to be examined;
- experimental simulation – laboratory test simulating a relevant part of the real world;

- field experiment – experiment carried out in a natural environment, but in which the researcher intervenes and manipulates a certain factor;
- field study – direct observation of "natural" systems, with little or no interference from the researcher;
- computer simulation – operating on a model of a given system;
- non-empirical evidence – argumentation based on logical reasoning;
- survey – collection of information from a broad and carefully selected group of informants; and
- qualitative interview – collection of information from a few selected individuals. The answers are more precise than those of a survey, but cannot be generalized to the same degree.

Figure 7 shows the eight strategies in a circle, divided into four groups:

I   The evaluation is performed in a natural environment.
II The evaluation is performed in an artificial environment.
III The evaluation is independent of environment.
IV The evaluation is independent of empirical measurements.

In the following, we shall take a closer look at the properties of these strategies and discuss which factors should determine our choice of strategy.
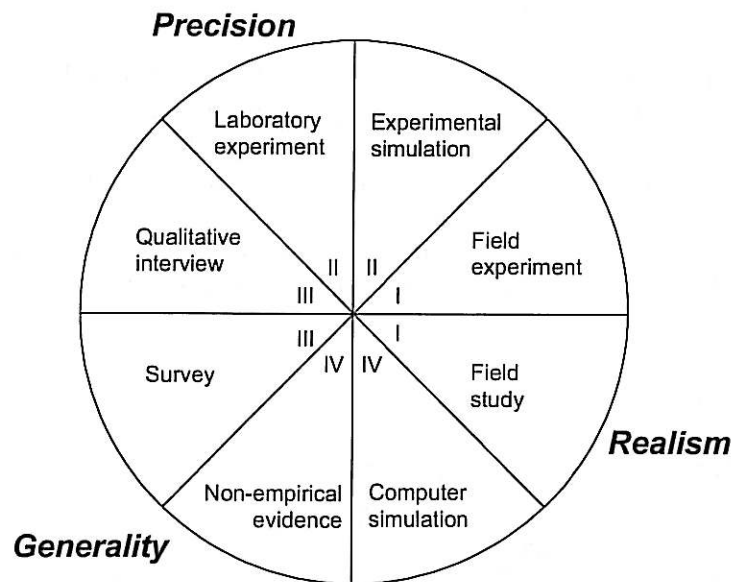

Figure 7: Evaluation strategies (after McGrath [12])

6.2 Which Strategy to Choose?

McGrath's figure also shows the three desired properties:

- generality – that the results are valid across populations,
- precision – that the measurements are precise, and
- realism – that evaluation is performed in environments similar to reality.

Obviously, the best choice of strategy would be that of a high score on generality, precision and realism altogether. That choice is, however, impossible in practice. The figure depicts this fact by placing the three properties far apart on the circle. We notice that laboratory experiments have a high score on precision, and that field studies have greatest realism. The greatest generality is found in surveys and non-empirical evidence. The solution must then be to *choose several strategies that complement each other*. When choosing strategies, the researcher has to decide among other things:

- *Is the strategy feasible?* Time and cost are two important constraints when it comes to selecting evaluation strategy. In addition we have the availability of the individuals who are supposed to participate in the evaluation. An experiment requires thorough planning and usually involves many people, and is therefore a costly strategy. The other extreme is computer simulation. Involving no human subjects, this strategy may be cheap and quick to carry out, if possible and relevant.

- *How to ensure that a measurement really measures the property it is supposed to measure?* The important thing is to isolate the property to be measured, and then account for all possible factors which might be supposed to influence the result. This topic is discussed in both text books and papers (e.g. [13], [14]).

- *What is needed to falsify the prediction?* Evaluation is nothing worth if a positive result can be given in advance, i.e. if falsification is impossible. Therefore, it is important to choose strategies that may, eventually, cause the prediction to be rejected, even if rejection would imply that the artefact is a failure.

Evaluation strategies may be regarded as tools by which the researcher can examine if the predictions are true. These tools give various possibilities, but also constrains. It is e.g. not feasible to test a system's functions by means of a qualitative interview (!). Hence, a dependency exists: When the researcher has chosen his/her tools (strategies), then the investigations (predictions) have been chosen also, at least to a certain degree. That is because the chosen evaluation strategies must have the potential to falsify the predictions. If not, the researcher either has to reformulate the predictions or choose other evaluation strategies.

7 Evaluation in Practice

7.1 Evaluation in Research and Development

We have already pointed out that technology research is similar to technology *development*. However, research requires the acquisition of new knowledge which is of interest to others, and which is documented in a way that enables re-examination (section 3.4). Whether we do research or development, a thorough evaluation is in either case important. This is the only way to document that the artefact actually fulfils the underlying need. Through evaluation, the researcher may collect arguments for the relevance of the artefact, while the developer may collect arguments for marketing and sale. For this reason, the developer as well the researcher should make use of the evaluation strategies presented in chapter 6.

The following sub-sections presents evaluation in two practical cases, the first one comprising several different evaluation strategies (section 7.2), and the second one handling evaluation within action research (section 7.4).

7.2 Evaluation Example – A New Nuclear Power Plant

This imagined example deals with the construction of a new nuclear power plant. We assume that most of the work to be done is technology development, although with room for some technology research. Because of the large complexity of a nuclear power plant, we shall concentrate on a few selected artefacts, which are the buildings, the control room and the reactor.

Security against Illegitimate Entrance

It is of utmost importance to control the admission to the power plant's area and to its buildings. Relevant measures are fences, guards, ID cards, cameras, etc. Imagine that the security officers have specified how the admission control has to be carried out. In order to decide whether the admission control is sufficient, one should combine several evaluation strategies, for example:

- laboratory experiment – robustness tests and dependability tests of ID cards;
- non-empirical evidence – a theoretical walk-through of the planned admission control systems, probably with references to similar installations;
- field study – an investigation of the implemented security measures and procedures, including their operations on a daily basis;
- field experiment – planned provocations in order to test the admission control systems, without the security guards' knowing.

Adequate Control Room

The control room of a nuclear power plant has to be arranged in such a way as to support effective monitoring and management of all the processes in the plant, included that of the reactor. Before the planning of the control room starts, it can be useful to collect experience from other nuclear power plants. That can be done by visits to selected nuclear power plants, accompanied by

- a survey – in which the questions are formulated in advance, facilitating comparison of the answers. Surveys do not require much time of each informant and may therefore be distributed to many persons;
- qualitative interviews – which are much less rigid and yield more detailed and precise information than a survey can provide. Performing qualitative interviews require a relatively long time and should therefore be carried out with a few, selected individuals.

Such collection of information about other control rooms may serve as evaluation of those control rooms, or rather, evaluation of the hypotheses underlying their shaping. At the same time, this information provides important input to the next research cycle about control rooms. It is just here, in the transition to the next cycle, that our example comes in.

Let us now imagine that relevant information has been collected, and that the new control room has been planned. One may save time and money by first building an artificial control room and experimenting with this one until everybody involved is content. Then, one may go ahead building the real control room. In the artificial control room, IT systems are used to simulate reality. Two types of simulation may be relevant:

- experimental simulation – simulating the reactor and the processes around it. The operators of the artificial control room interact through IT systems with a reactor simulator instead of a real reactor. This is a technique often used to optimize control rooms with regard to potential accident scenarios;
- computer simulation – simulating the operators in addition to the reactor and its related processes. Simulating the operators means to translate human actions into actions that are

performed by a computer. The person responsible for the simulation will compose several action sequences in advance, each sequence simulating one type of human behaviour.

Efficient Reactor

The fuel rods in the reactor have to be constructed in such a way that they give optimal effect. New types of fuel rods are tested in a laboratory before they are set going. Laboratory experiments give the researcher the opportunity to test one variable at a time while keeping the other variables constant.

7.3 What Do We Learn from the Power Plant Example?

The above examples show that the evaluation principles apply to both research and development. However, neither researchers nor developers are able to fully verify their results. Rather, they test their hypotheses through a number of predictions by means of the evaluation strategies at hand.

7.4 Evaluation Example – A New Method for Risk Analysis

As pointed out in chapter 5, action research has the following characteristics: The researcher introduces changes in an organization or process, the researcher is a part of the object under study, and the other participants contribute to the research. A question that naturally comes up is *how the researcher should go about examining his/her own behaviour*. Below is a real-life example of how this may be done.

A research team has developed a new method for risk analysis. This method includes a new graphical language for expressing assets, threats, vulnerabilities, probabilities, etc. During the project, the research team performed a first iteration resulting in the first version of the method. In this iteration, one carried out simple field experiments or experimental simulations in order to evaluate the method. This approach was not action research, but ordinary technology research.

Later on, the method has been further developed and evaluated in several large companies. These new iterations have been carried out as action research. The researcher's intervention has been to introduce the new risk analysis method in an organization, adapting it to new requirements and local needs. These new requirements and needs have often been expressed during the risk analysis meetings. Thus, the researcher's capability to improvise has had a great impact on the result, together with the other participants' goodwill and receptiveness to new approaches. A survey has been central in the evaluation, querying both the appropriateness of the method and the behaviour of the researcher during the risk analysis meeting. Afterwards, the researcher has critically gone through the results of the survey plus his/her own experiences from the meeting. The result of each iteration has been a report suggesting improvements to the method, both regarding the development of the language, and when it comes to the practical use of the method in risk analysis meetings.

7.5 What Do We Learn from the Risk Analysis Example?

There are two important things to learn from the example above. Firstly, it is the intervention of the action researcher *together with* the clients' participation that generate results. Secondly, it is worth noticing that not all evaluation strategies are equally fit for action research. The most appropriate strategies are:

- field experiment – because the researcher is going to intervene;
- survey – because there are often many persons involved; and
- qualitative interview – because this strategy generates more thorough and precise information and therefore should be used in addition to a survey.

8   Conclusion

In both classical research, technology research and action research, the starting point is an overall hypothesis on the form "B solves the problem A". In classical research A is a need for new theory, in technology research A is a need for a new artefact, and in action research A is a need to improve an organization's processes/systems. In all three variants, the overall hypothesis has to be specialized to more concrete hypotheses, which in turn are used as the basis for predictions. A prediction is a statement about what will happen (under given circumstances) if the hypothesis is true. The researcher tests the predictions by means of various evaluation strategies, which should be combined in order to yield credible results.

Thus, classical research, technology research and action research are closely related. All three variants are performed during iterations of the three main phases:

1. *problem analysis* – resulting in a description of the need, i.e., the problem;
2. *innovation* – resulting in a solution to the problem and an overall hypothesis; and
3. *evaluation* – resulting in an argument for the validity of the overall hypothesis.

Action research may be understood as a special case of technology research, in which the artefact is an organization, and in which the researcher forms part of the research object.

The main message of this report is that technology research does follow a principal method, and that this method has many points of resemblance with that of classical research. Furthermore, the authors wish to inspire technology researchers to use this method more deliberately, from the belief that the method makes technology research more efficient. This is because the method reminds the researcher *what* to do, *when* to do it, and *why*.

However, things do not always proceed smoothly. Premises may fail, hypotheses may have to be rejected along the way, and conditions that nobody had ever thought of, may be discovered. In such situations, the work may seem to be at a loose end. But in moments like that, the research method may come to one's rescue. To unravel the tangle, the researcher should start a new iteration by reformulating the problem and asking what is the actual need.

9   Acknowledgements

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