# Students' Understanding of Computer Networks in an Internationally Distributed Course

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## Abstract

*The different ways in which concepts within computer networks are understood by master level students who take an internationally distributed project-based course have been identified in an empirical, qualitative, phenomenographic research project. Students, working in teams of six, three in each of the participating countries, collaborate to produce a software system to control a modified version of a toy. The students' learning of a computer networking protocol is presented in this paper, as well as a discussion on the generalisability to other groups and other situations. Teaching, based on this kind of results has been showed to render a considerably better learning outcome. The results are also useful when studied in the light of the students' learning environment, since relations between the learning outcome and the learning environment can be discerned. This offers insights to be used in the design of distributed courses.*

## 1. Motivation

An understanding of how her[1] students understand the concepts that she is teaching, is a valuable tool for a teacher. With such an understanding as a background, she can design labs, develop projects, choose examples, and create lectures, that help a larger number of individuals to learn better about the concepts she is teaching.

With an overall aim of improving computer science education the questions addressed in this research project concern how students, who take an internationally distributed project-based course in computer systems, understand and learn about some concepts related to computer networks, and how their learning is related to the collaboration and the learning environment.

This paper focuses on the various ways in which a technically advanced concept, Remote Method Invocation, RMI, is understood. RMI is used in computer communication, as a protocol (a set of rules) that provides programmers with a facility to supply data to code residing and executed on a remote machine, and to receive results through a "method" invocation mechanism in the Java language. Through qualitative research, performed using a phenomenographic research approach [12], a limited number of qualitatively different ways of understanding RMI are identified and described. Pang [13, 14] has shown that students taught with such phenomenographic results taken into account show considerably better results than control groups.

The results presented in this paper describe the learning outcome in a project based course, where university students in computer science study and work in groups where three of the six group members are in Sweden, while the others are in the US. Each group should produce a software system to control a motorised, computerised toy.

As pointed out in the extensive survey by Lehtinen et al. [11], relatively few studies focus on the learning outcome in distributed learning environments. Instead, most published work concentrates on tools for collaboration, or on different aspects of the collaborative process. Dillenbourg et al. [9], as well as many others, argue that this is partly due to the fact that it is "almost impossible to establish causal links between the conditions and the effects of a collaboration" (p. 189). Koschmann [10] follows the same line, stating that "a [...] view of learning and instruction, one that brings [...] social issues into the foreground as the central phenomena for study" (p. 11) is the current research tradition, or paradigm. This project is partly related to this tradition, but has a stronger focus on students' learning within the subject area.

In the current work the students' understanding of a computer networking concept, used within their project, are analysed and described in a qualitative way. The students' understanding and learning of these concepts are, in a complex way, intertwined with the their experience of the learning environment. These relationships between the students, the subject area and the learning environment forms the core of the project [3].

The outcome of the research project, of which the study presented in this paper is a part, is an analysis and a description of factors in the relationship between the student, his/her learning, and his/her study environment. From these findings insights can be gained that help a teacher or a course designer to develop courses of this kind.

Qualitative research approaches are "multimethod in focus, involving an interpretive approach to its subject matter. This means that qualitative researcher studies things [...] attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them." [8], p. 2. A researcher can thus make interpretations of complex situa-

1. A teacher will in this paper be referred to as "she". Of course, the same reasoning would apply to a male teacher

tions that might show to be more valuable in course design than casual relationships between particular variables.

## 2. The qualitative research approach used

As this research explores how students understand some computer network concepts with an aim of improving teaching and learning and learning in computer networks, the choice of a research approach, or research methodology, becomes important. The research approach selected should be open to the students' different understandings, without presupposing particular structures or ways of thinking. At the same time, an approach should offer rigorous, sound and well-researched ways to collect and analyse data, to describe the results, to deploy the results into the educational situation, and to judge to what extent the results can be trusted and generalised to other groups and other situations. In this situation, phenomenography (Marton and Booth [12]), is an appropriate choice.

### 2.1. Phenomenography

Phenomenography has its roots in work performed by Marton and his colleagues, and has proved successful in research on learning in higher education. Examples from different fields of learning, and with different focuses, include [1,2,4,6,13].

Phenomenographic research aims at identifying, analysing and describing the different ways in which a phenomenon, in this study RMI, is understood within a group of students. The results of a phenomenographic research project are based on empirical data, normally collected through interviews, and offer a description of a small number of qualitatively different categories, each category summarizing and describing a particular way of understanding the phenomenon under investigation.

The results are interpreted at a collective level, describing which understandings there are in a group, without relating a particular way of understanding the phenomenon to a specific individual or group of individuals. Phenomenography does not offer quantitative results, since individuals' understanding of something change over time, when he or she is learning, thinking or discussing. The result of the research, being a description of the various ways in which a phenomenon is understood by a collective of learners, is thus shaped by, and related to, both the learners and the phenomena they study, here RMI. Learning is defined as understanding something in a new way, or as simultaneously understanding something in new qualitatively different ways.

The strong focus on the content of the subject area (here computer networks), offers good possibilities to deploy the results in education within that particular field. Several authors (Adawi [1], in physics; Berglund [2], in computer networks; Booth [4], in programming; Cope [6], in information systems; Pang [13], in business economy) have described this as a key feature of phenomenography. It is also an important reason for choosing phenomenography for the current project.

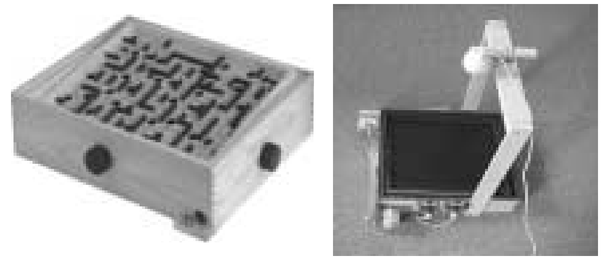

Figure 1.Figure 1. The Brio toy used in the project, in an original version (to the left), and modified (to the right)

### 2.2. The research process

Phenomenographic research is not performed in controlled experiments, but in "close proximity (both spatial and conceptual) to the learning situation [in which the students] find themselves" [5]. Data is normally collected through interviews with students, selected to represent different backgrounds, interests, attitudes towards the subject area, previous study results etc. Properly conducted interviews contain a rich number of different utterances about the phenomenon in focus.

As was indicated above, a phenomenon can be understood in numerous different ways. However, phenomenographic research has shown, as indicated in Marton and Booth [12], that these different understandings can be categorized in a limited, often small, set of qualitatively different ways of understanding the phenomenon. The aim of the analysis of the data is to identify such a set of categories, where each category describes a particular way of understanding the phenomenon under investigation, and where the categories together form a whole. During the analysis of the data, during which the students' statements from the transcribed interviews are read and reread, their utterances are classified into a limited set of qualitatively different categories The categories are not predetermined, but are instead created during the analysis. An utterance from one student can here be set in relation to other statements from the same student, as well as in relation to statements from other students. The students, from whom the data stem, then come to serve as "carriers" of the different understandings, and are not visible as individuals in the results.

## 3. The course setting

As was mentioned in the first section of this paper, the research is performed in an internationally distributed project course. The course, which had 96 students during the year of this study, is a part of a joint research, development and teaching initiative, the Runestone initiative [2], [7]. Teachers and researchers at the two universities have collaborated with researchers at four other universities, forming a research network.

During the course, each team of six students develops a software system that gives an end-user the possibility to "play" with a Brio labyrinth [2]. The labyrinth, see figure 1, is a Swedish wooden toy, the aim being to manoeuvre a

Table 1. Aspects of the different categories that describes RMI

| Category number | In which framework is RMI experienced? | | As what is RMI experienced? | What is the technical characterisation? | How is RMI described? |
|---|---|---|---|---|---|
| 1a | Two specific computers | Two computers with undefined roles | RMI is related to data transfer | Not clearly articulated | In concrete terms |
| 1b | | Two computers with different roles | RMI is something more than transfer | Not clearly articulated | |
| 1c | | Two computers with well-defined roles | RMI is for using resources | Sub-programs on another computer that is called | |
| 2. | An internet | | RMI is for sharing resources on an internet | Interacting independent program objects on virtual machines | In an abstract way |
| 3. | A world outside computer network | | RMI is a standard tool | Not articulated | From an outside perspective |

steel ball from a starting point to a final point on the board, by tilting it so that the ball moves without falling into any of the holes. The original labyrinth has, as is shown in the left hand picture of figure 1, knobs that are used to control the angle of the board. The labyrinth used was modified to have step-motors to control the board and a camera to give feedback to the controlling software system, as in the right hand picture.

The task, being complicated for the student teams, demands good skills of computer systems. Particularly, the design of the modified toy contains several computer communication tasks. The choice how to tackle these, and discussions about the relative advantages of different communication protocols and tools are important tasks during the students design of the solution. Later, during the coding, many of the problems the students have had can be related to computer communication.

## 4. Qualitatively different ways of understanding RMI

Due to the important role of computer communication, and the use of several different computer network protocols within the student project, computer communication was selected as a main theme in the study, of which this paper is a part. The presentation in this paper will focus on RMI. Data was collected through interviews, and the students were asked to describe how they understood different concepts and protocols.

The opening question was normally “What is RMI?” followed by questions aiming to further explore the interviewee’s understandings. As a result of the analysis, three qualitatively different ways of understanding RMI have been discerned and categorized in the group of students.

The aspects that differ between the three ways in which RMI are understood are:

1. of which framework, or of which scope, as RMI is a part,
2. how, or as what, RMI is understood,
3. in what technical ways RMI is characterised,
4. and in what way RMI is described.

The differences are closely related and form three categories, as shown in the rows of table 1, where the rows correspond to the categories.

An important, or critical, difference between the categories is, as indicated in the first column, the framework, or territory, in which the students understand the protocol to be used.

The framework could be understood as a part of an environment that consists of two communicating computers (category 1), as a part of an internet (category 2), or as belonging to a world that goes beyond computers (category 3). The first category can be further analysed into three different subcategories. Here we differentiate between the roles the two computers play in the communication. Undefined roles in the first subcategory (1a), different but not clearly specified roles in the second (1b), and finally, differentiated and well defined roles in the third (1c).

The second column indicates what RMI “is” as seen by the students, while column 3 presents the technical characterisation of RMI. Finally the last column describes the different ways in which the student talk about RMI: as something concrete, in an abstract way, or from an outside perspective.

The variation in the different aspects, which are discerned in the empirical material and presented in the columns of Table 1, is not randomly correlated. In fact, data shows that a few different understandings exist, corresponding to the rows in Table 1. Each row then comes to describe a particular way of understanding RMI. These results are well in line with phenomenographic research results in general as indicated in Marton and Booth [12].

## 5. Examples from the empirical material

While the preceding section presented the different ways in which RMI was understood by the students, this section gives some examples of interview excerpts, adapted from [2], and indicates their interpretation. It must be stressed, however, that this section only offers examples and glimpses of the data, and does not on its own justify the conclusions drawn. As described in section 2, the set of interviews, as a whole, forms the basis for the analysis.

In sub-category 1c an understanding of RMI in a framework of two computers is expressed, where RMI serves as a tool to execute programs on another machine and in that way to use the resources of another computer.

Staffan[2] gives a description in concrete terms of his perceptions in regard to RMI. During the an interview he says:

Int: RMI?
Staffan: Oh, that's Java's version of client server, it has a stub and a skeleton which one uses. You send from your client ... you can fetch and allow to execute things from the server via. It feels as if they are local on your ... on your client, but you execute from the server actually.

Staffan is saying that RMI is used on two computers, a client and a server. The client can execute a program on the server. This program is used as if it were residing on the client. In the beginning of his explanation, he talks about a stub and a skeleton. This, together with the fact that he talks about the role of client, indicates that he understands RMI as integrated with the two computers that are used in the communication process.

In category 2 the framework that forms the basis for the category of description is different. Rather than the two computers of the previous category, RMI is seen as an integrated part of an internet, and is understood as a way of using or sharing resources on the network.

In the excerpt below, taken from an interview with Axel, this perspective is clearly visible.

Int: We have talked about RMI. OK what is RMI?
Axel: RMI is Remote Method Invocation which is basically, you have a Java object on one machine somewhere, it doesn't matter where, and then you have a Java object on another machine somewhere, it doesn't matter where. And then you can, either one can call the other, or they can each call each other um. It's, basically, you have to register the object in the RMI registry and then essentially it works just like the other object on the same machine. It is a little bit slower than maybe a socket would be, but it's fairly stable if you can get the security issue right.

Axel explicitly says the objects that call each other may be on any machines. It is not important to him where they are, they can be anywhere on Internet. Having one object call another, or having two objects call each other, implies that they use each others' subprograms. Axel shows an understanding of RMI where the protocol is seen as a way to use resources in a framework of the Internet.

In category 3, RMI is understood as a standard tool and is experienced as a part of a framework that goes beyond a computer network and that is described from an outside perspective.

In the excerpt below, Adam discusses the choice of TCP, another network protocol, instead of RMI, for all communication throughout the code of the project:

Adam: Between, like the game server and the video and motor, you mean? [...]
Int: And you will just accept that they are TCP. So what you do is that you go for overall a TCP solution. OK Ya.
Adam: Right. And it's my impression that it doesn't matter what one part communicates in, because if it is communicating with RMI to the client, but with TCP to the motor, I mean it's just different ways of formatting the information, in a sense, so..
Int: Ya, ya.
Adam: If it isn't TCP, you know, it doesn't really affect..

2. The names on the students are changed in this paper to protect the anonymity of the students. Since there are few women taking the course, they are also given boys names in this paper.

Adam argues that RMI and TCP are different ways of formatting the information. He mentions communication with the motor and the technical communication between the server and the client. The choice between the protocols, seen in this perspective, is not important, continues his argument. He talks about the two protocols as two different ways of formatting data and as two different instances of the same phenomenon. The comparison that he makes requires him to reason about the protocols from an outside position, where properties of individual protocols are abstracted; that is, he talks about RMI from an external perspective.

## 6. Relevance and generalisability of the results

The research approach used in this project, phenomenography, offers intellectual tools that guide the research and that indicate a sound and rigorous process, and offer ways to judge the quality of the findings. Numerous phenomenographic research projects around the world also puts a standard for good research. The findings of this study can be related to the results of others. A comparison indicates that these results are consistent with findings of others (see for example[1], [4], [6]).

The results in this project are consistent within themselves, in that the results for RMI both resemble, and differ from, the results for other computer network protocols such as UDP, TCP, and the general concept of network protocols, in relevant ways [2]. The categories understandings of RMI also form a logical structure, where each new understanding expresses a wider context, or territory, for the network, a more complex understanding of what RMI "is", as well as a more abstract way of discussing the network. This structural property also points towards the consistency of the results [12]. The results are complete, in the sense that all interview excerpts have been characterised. There were no "left-overs" that could not be clearly related to any of the categories.

The results have been discussed at different stages with colleagues, both within computer science and educational research. These discussions, together with the possibilities to judge and compare results offered by phenomenography, indicate that the results present a good description of the understandings of RMI that can be found within the student cohort.

The results can also be assumed to be relevant for other groups of advanced computer science students for several reasons: The students, who took part in this investigation, had studied computer networks before or in parallel with the project, as well as other aspects of computer science for at least two and a half years. The results are thus not only related to the course that is central to the investigation, but also to their whole learning experience as computer science majors. Since data has been gathered from two different universities in different countries, and yet no systematic differences have been identified in the understanding of RMI, this offers strong indications that the results are generalisable.

The fact that the object of research is the *variation* in the ways in which RMI is understood is important for the generalisability of the results. As indicated earlier, these results do not reveal the distribution between different understandings. Results based on an analysis at a collective level of a stable phenomenon (RMI does not change much over time) tend, as demonstrated by phenomenographic research, to be relatively stable over time and over different groups. Similar ways of understanding something often appear in different groups, and normally do not change very much. Instead the distribution between the different understandings can vary largely. The studies of the experience of learning described by Marton and Booth [12], where similar categories are discerned in different studies, can serve as an illustration of this stability.

This analysis of the results and the discussion relating my research to the framework of phenomenography, supports the claim that the results are of a good quality and relevant for other, similar student cohorts.

## 7. Applications of results

An important question to ask, when discussing the applicability of the results, is whether certain ways of understanding RMI are “better” than others. To address this issue, the categories found are related to the different tasks in a programming development project [2].

RMI understood as related to two computers, and described in concrete terms (category 1) is useful for programming tasks when the interaction and between two specific machines must be considered. The abstract descriptions of the properties of RMI (category 2), understood as a part of a network, relate to program design and selection of which tools or protocols to use in a particular project. Finally, the understanding expressed in category 3, where RMI is discussed from an outside perspective, is useful when discussing what properties protocols could have and thus to design new protocols. It follows that the different ways of understanding RMI are relevant in different situations in a software development project. None of the understandings of RMI are more valuable than the others, when seen in isolation. The task at hand instead indicates which understanding is a useful tool. This argument is developed in more detail in a fortcoming paper.

A teacher should then encourage the students to understand what is taught in different ways, by creating a variation, as proposed by Pang [13]. In this way, the teacher helps her students to get the tools for coping with the different tasks in the stages of a program development cycle.

## 8. Conclusions and future work

The outcome from this project, describing the various ways in which a computer network concept is understood, is also set in relation to the complex, computer-supported distributed learning environment. Here focus is on the learning environment as it is perceived by the students. Changes made in a course, must, in order to improve learning, be experienced as useful by the course participants. A theoretical framework for analysing and describing the complex relation between the students, the outcome of the learning, and the learning environment, as percieved by the students is proposed by Berglund [3]. Applications of this framework will be the focus during the continuation of this project, and results will be presented at later conferences.

The results presented in this paper have direct applications in teaching situations in computer networks, both teacher-led teaching situations and project works, as well as in a larger context in research about learning in computer-supported, distributed projects. The coming results from such projects can be used to design distributed courses, where students collaborate using different technical tools.

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