

Academia-Industry Collaborative Research Project

- A case study of the ACTA-DelltaTech collaborative research on the training effectiveness of the SIMENDO dental training simulator



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MSc Science Education and Communication

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1 Introduction

1.1 ACTA-DelltaTech collaborative research project

The investigator of this study participated in a collaborative research project between Academic Centre for Dentistry Amsterdam (ACTA) and a small sized enterprise named DelltaTech during the period from June, 2009 to December, 2009. Her role in that project was a key research student, who represented DelltaTech and collaborated with another research student assigned by ACTA. There were also two supervisors involved in that project to guide the two research students to conduct the research, with one from ACTA and the other from DelltaTech.

ACTA is one of the first users of the new 3M Lava™ Chairside Oral Scanner. The required hand-eye coordination to efficiently move the scanner over the patient's teeth is cumbersome and requires training. For this purpose, earlier ACTA asked DelltaTech to develop a training simulator which could be incorporated into a dental curriculum. The research under the collaboration between ACTA and DelltaTech was initiated when DelltaTech finished the prototype of the simulator, with the aim to validate the training effectiveness of the simulator. As DelltaTech's client and collaborative research partner at the same time, ACTA would decide whether or not to further invest in the simulator development based on the research result. At the end of that collaborative project, the research failed to prove the training effectiveness of the SIMENDO simulator. ACTA claimed that they decided not to further invest in the simulator development with regard to that research result. However, DelltaTech insisted that they were not satisfied with the research project in collaboration with ACTA with arguments including but not limited to:

- The expectations of different stakeholders on this collaboration were not well managed;
- The project progress was not regularly updated to each partner.

DelltaTech's dissatisfaction of that collaborative research project initiated an evaluation of that collaboration practice and a study of how to increase the probability of academia-industry collaborative research projects success.

Therefore there are two research topics coming out of the ACTA-DelltaTech collaborative research project that we have interest to explore, which are:

- I. Validation of the training effectiveness of the SIMENDO dental training simulator;
- II. Success of academia-industry collaborative research projects.

1.2 Validation of medical simulator

With current software, it is possible to design any number of virtual environments to simulate a variety of tasks. The difference between a useful simulation and a mere computer game based on a medical scenario is the degree to which the exercise meets the validity criteria (Desser, 2007).

Although the importance of simulation as an educational tool for teaching surgical technical skills is increasingly recognized in the medical community, literature examining the efficacy of simulation-based training remains inconsistent and limited (Aucar et al., 2005 & Van Nortwick et al., 2009). One reason for this variability and limitation is the lack of rigor involving psychometric measurements reported in studies of SBT interventions (Van Nortwick et al., 2009). A comprehensive qualitative review by Feldman et al. (2004) concluded that "significant design flaws" in the reviewed studies caused a "lack of standardization in tasks, metrics, and level of validation". Deficiencies and heterogeneity in validation study methodologies have been cited repeatedly as major limitations to drawing strong conclusions comparing the effectiveness of SBT and evaluating the transfer of skills from the simulation setting to the operation room (Sturm et al., 2008). The recent Cochrane review of randomized-controlled trials investigating the effectiveness of SBT concluded, "Research of higher methodological quality is needed" (Gurusamy et al., 2009). Therefore, within research topic I we look into simulation-based training with particular attention to its validation methodology as well as examine the training effectiveness of the SIMENDO simulator.

1.3 Academia-industry collaboration

There is a growing world-wide trend toward greater collaboration between academia and industry, which is confirmed in several studies (Kozlowski, 1999; Barnes, 2002; Butcher & Jeffrey, 2007). This type of collaboration provides excellent benefits for both partners. For universities, industrial companies can offer financial security and excellent research resources (Kozlowski, 1999). Meanwhile the benefits offered to the industry by such type of collaboration include access to considerable and unique expertise not available in-house. Furthermore, the collaboration has eliminated the need for industrial partners to recruit permanent staff to pursue a project (Kozlowski, 1999).

However, these considered potential benefits are often not realized in practice according to Barnes's observation (2002). The major reason is that collaborations between diverse organizations usually do not get enough management effort to be successful (Dodgson, 1999).

1.4 Project communications

Without effective communications, you simply can't expect a high-performance team working on a project. Like it or not, communication is the most important component with in any project (Charvat, 2002). Therefore, we intend to seek for solutions within the 'project communications' domain to improve the academia-industry collaborative research project.

1.5 Research questions, aims and scientific relevance

So far it is clear that we intend to study the ACTA-DelltaTech collaborative research project within three domains:

- Validation of medical simulator;
- Academia-industry collaboration;
- Project communications.

Within each domain we intend to achieve one goal, which brings to three main objectives of this research:

1. To validate the training effectiveness of the SIMENDO dental training simulator;
2. To evaluate the ACTA-DelltaTech collaborative research project from the collaboration point of view;
3. To give recommendations on a more effective management of academia-industry collaborative research projects from the communication point of view.

Following the above-mentioned objectives, we formulate the main research question:

How can communication contribute to increase the probability of academia-industry collaborative research projects success – based on the case study of the ACTA-DelltaTech collaborative research project?

In order to answer this main research question, the research is divided into two parts. In Part I, we focus on the ACTA-DelltaTech collaborative research on the validation of the training effectiveness of SIMENDO simulator. Next, in Part II we focus on the evaluation of the ACTA-DelltaTech collaboration practice and the design of a communication plan for the academia-industry collaborative team. With each part, several sub-questions are also formulated:

Part I

1. What is the training effectiveness of the SIMENDO dental training simulator?

Part II

2. What are the key factors of academia-industry collaborative research projects success?
3. How is the ACTA-DelltaTech collaborative research project with regard to those key factors?
4. How can communication contribute to increase the probability of academia-industry collaborative research projects success?

With these sub-questions, our aims are:

Part I

1. To assess whether training on the SIMENDO simulator will improve trainees' performance on a real oral scanner;

Part II

2. To identify the key factors of academia-industry collaborative research projects success based on the published literature and to construct a framework for those identified factors;
3. To evaluate the ACTA-DelltaTech collaborative research project from the collaboration point of view;
4. To give recommendations on a more effective management of academia-industry collaborative research projects from the communication point of view.

At the end of this research, DelltaTech, as one of the initiators, might benefit from it:

- An early-stage product evaluation of the SIMENDO simulator;
- A comprehensive evaluation of the ACTA-DelltaTech collaboration practice;
- A strategic communication plan for the collaborative research project team in the future.

1.6 Outline

In Chapter 2 we present the validation study of the training effectiveness of the SIMENDO simulator.

In Chapter 3 we present an overview of the multiple research methods applied to study sub-question 2, 3 & 4.

In Chapter 4 we start out with a systematic literature search to identify the published literature relevant to sub-question 2. Next we construct a theoretical framework for the key factors of academia-industry collaborative research projects success based on a literature review.

In Chapter 5 we further develop the theoretical framework constructed in Chapter 4 into an analytical framework that we can apply to evaluate the ACTA-DelltaTech collaboration practice. The evaluation results are presented afterwards.

In Chapter 6 we follow a staged plan to set up a strategic communication plan for the academia-industry collaborative research project team.

In Chapter 7 we draw conclusions of the whole research by giving the answer to the main research question. Discussion of this research and implications for future research are presented in the last two sections of this chapter.

The outline of this thesis and the chapter in which each sub-question is answered is visualized in Figure 1.

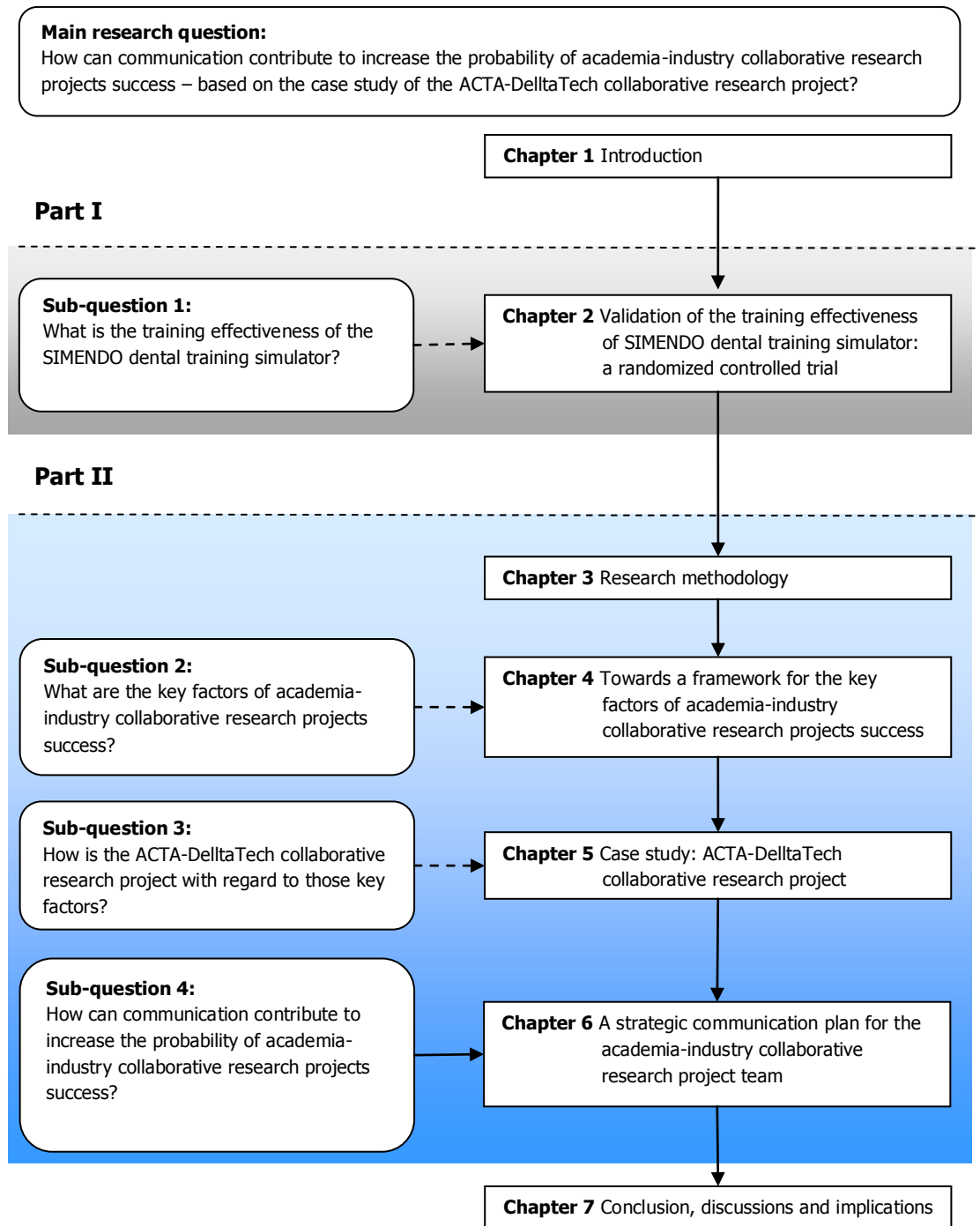


Figure 1 Thesis outline: chapters and answers to (sub-) questions

Part I

2 Validation of the training effectiveness of the SIMENDO dental training simulator: a randomized-controlled trial

2.1 Introduction

In this chapter, we aim to assess whether training on the SIMENDO dental training simulator improved the trainee's performance on a real oral scanner. We define the improvement of performance as the shortening of the time required for oral scanning. This chapter is presented in the format of a standard scientific paper with the following sections: 'Materials and methods' (§2.2), 'Results' (§2.3) and 'Discussion' (§2.4).

2.2 Material and methods

2.2.1 Apparatus

Two apparatuses were used in this study. The clinical oral scanning took place on the 3M Lava™ Chairside Oral Scanner (C.O.S.). And the training session took place on the SIMENDO dental training simulator.

3M Lava™ Chairside Oral Scanner

The Lava C.O.S. from 3M ESPE (Figure 2) is a digital impression system that helps solve the challenges dentists experience with traditional impressions such as delamination, facial lingual pulls, tearing at the margin, tray-tooth contact and stone model discrepancies. More information about this oral scanner can be found on 3M website¹.



Figure 2 3M Lava™ Chairside Oral Scanner (left) and an oral scanning with 3M oral scanner on a phantom head

¹ http://solutions.3m.com/wps/portal/3M/en_US/LavaCOS/3MESPE-LavaCOS/

SIMENDO dental training simulator

SIMENDO dental training simulator (Figure 3) is developed by DelltaTech. It is a model which simulates 3M Lava™ Chairside Oral Scanner and designed to train eye-hand coordination skills required for oral scanning, by using abstract tasks such as camera navigation, basic scanning such as plane scanning and side scanning, and full scanning.



Figure 3 SIMENDO dental training simulator

2.2.2 Randomized-controlled trial

Randomized-controlled trial (RCT) was identified as the appropriate experimental design for the SIMENDO simulator validation study in a literature study which was conducted prior to this research. The full report of that literature study can be found in Appendix. Within that literature study, we not only argued why RCT is the appropriate experimental design for our study purpose but also constructed a framework for an RCT design.

2.2.3 Study population

Institutional research approval was obtained at the beginning of this study. 12 dental trainees of the 5th year at Academic Centre for Dentistry Amsterdam (ACTA) who enrolled for the course KREST² participated in this study. Subjects with prior experience in oral scanning (either on a simulator or a real oral scanner) were excluded. All subjects were not informed of the purpose of this study.

2.2.4 Study design

Within the literature study mentioned before, we also developed a study design with the core of an RCT design to examine the training effectiveness of the SIMENDO simulator (Figure 4). First all subjects watched a video introduction to 3M Lava™ Chairside Oral Scanner prepared by the investigators to ensure a standard level of background knowledge with regard to instrument handling and oral scanning procedure. Next each subject was given an opportunity to practice handling the oral scanner and scanning following the procedure. Such a practice was intended to correct the wrong instrument handling or oral scanning of the subjects.

² KREST: a course which teaches students the deep disciplines of restorative dentistry.

Then all the subjects were immediately pretested on the oral scanner. They were asked to use the oral scanner to do two quadrants scanning on a phantom head. The selected quadrants were Quadrant 3 and Quadrant 4³. The oral scanning procedure should strictly follow the instructions, which required the scanning to start from the end of the quadrant to its front, then move backwards to its end, and turn to the inner side and then the outer side. The time for each subject to finish the oral scanning of Quadrant 3 and Quadrant 4 was separately measured and recorded.

After the pretesting, 12 subjects were randomly assigned into two equal-sized groups (n=6): (1) the intervention group that received simulator training and (2) the control group that did not receive any training. Tasks incorporated in the SIMENDO simulator that were selected for the training session were 'plane scanning' and 'side scanning' (Figure 5), as the feedback from the pilot study subjects indicated that 'plane scanning' and 'side scanning' were the two most essential tasks for the mastery of oral scanning while relatively easier for the non-experienced to start with.

Within the training session, each subject from the intervention group was asked to perform a number of repetitions of 'plane scanning' and 'side scanning'. A certain level was set for subjects to reach within the training session, which was each subject had to pass the 'plane scanning' test and 'side scanning' tests incorporated in the SIMENDO simulator twice, but not necessarily consecutive. The number of repetitions a subject performed in the training session depended on when (s)he reached the predefined level. A maximum of 5 repetitions was also set for the training session. Once the subject reached the level, the training session stopped immediately. However, if the subject used up 5 repetitions for certain task while still did not manage to pass its test, the training session also stopped. Other rules included in the training protocol are:

- When subjects are performing the task, investigators are not allowed to give any instructions to them. Instructions can only be given once the performance is done if necessary.
- When subjects from the intervention group are receiving the training session, subjects from the control group are not allowed to attend or view the session.
- Inter-subject communication, in any form, is not allowed.

After the training session, a short break of 10 minutes was given to all subjects. Then they were posttested on the oral scanner. The posttesting tasks were the same as those of the pretesting. Subjects were asked to perform an oral scanning of Quadrant 3 and Quadrant 4 on a phantom head, strictly following the instructions concerning oral scanning procedure. And again the time for each subject to finish the oral scanning tasks was separately measured and recorded.

³ Quadrant 3 and Quadrant 4: the left half and the right half of the lower jaw.

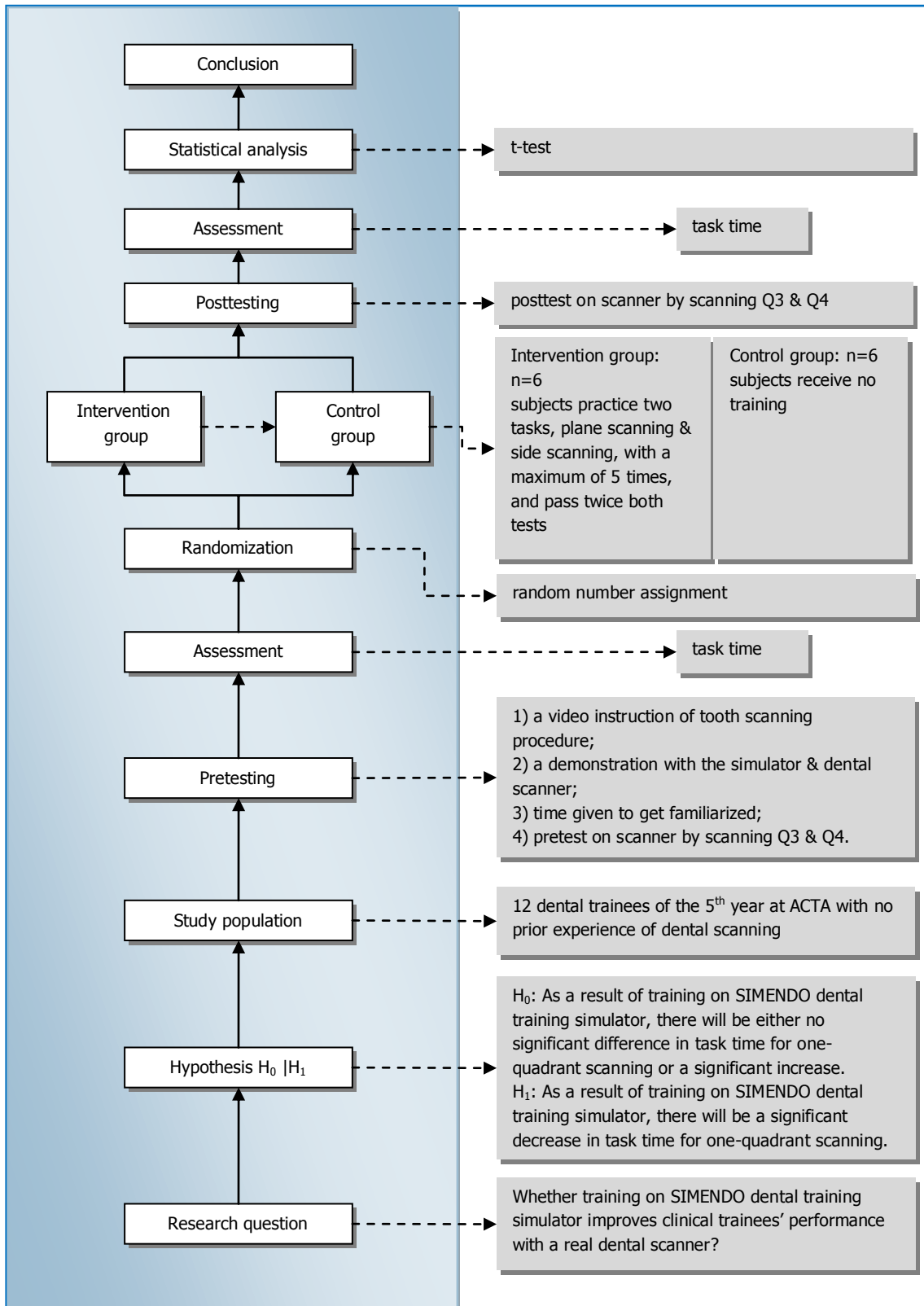


Figure 4 Research design with a core of RCT design for the validation study of the training effectiveness of the SIMENDO simulator

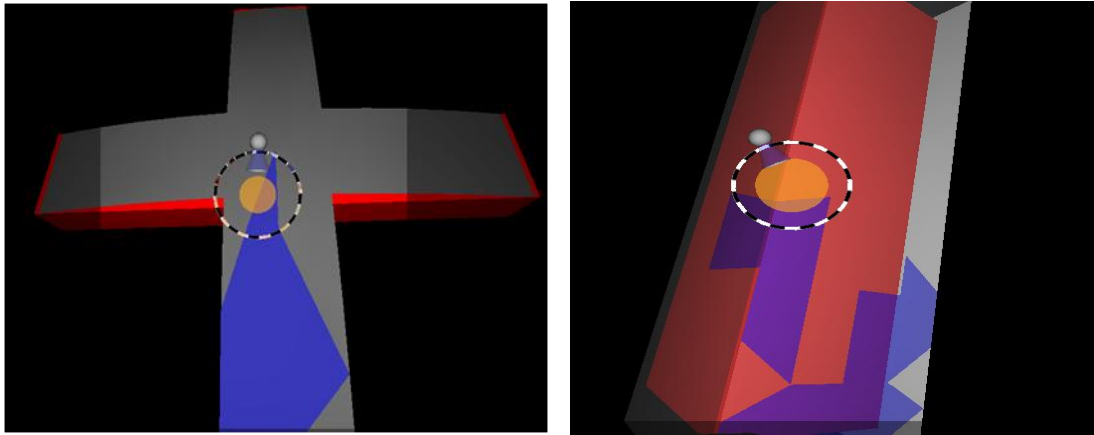


Figure 5 Basic scanning tasks of SIMENDO dental training simulator: 'plane scanning' (left) and 'side scanning' (right), with the aim to teach the basic eye-hand coordination required to efficiently move the scanner around objects (teeth)

2.2.5 Assessment

Two investigators reached an agreement on the criteria of a qualified one-quadrant oral scanning. And the time taken to finish the task of a qualified one-quadrant oral scanning was used to assess the performance.

2.2.6 Statistical analysis

Performance of the intervention group and the control group was compared by using t-test.

2.3 Results

Twelve dental trainees participated in this study, with 6 subjects in each group. And all of them completed the entire study. The time of each oral scanning is presented in its corresponding scheme in Figure 6, according to

- whether it was performed on Quadrant 3 or Quadrant 4;
- whether it was performed in pretesting or posttesting;
- whether the subject who performed it was from the intervention group or the control group

The t-test result of the one-quadrant oral scanning time in the pretesting (Table 1) showed that there was no significant difference between the two groups in terms of oral scanning skill prior to the training session, with the average one-quadrant oral scanning time of 195.18 seconds (SD 118.56) for the intervention group and 155.95 seconds (SD 37.96) for the control group ($P=0.46$).

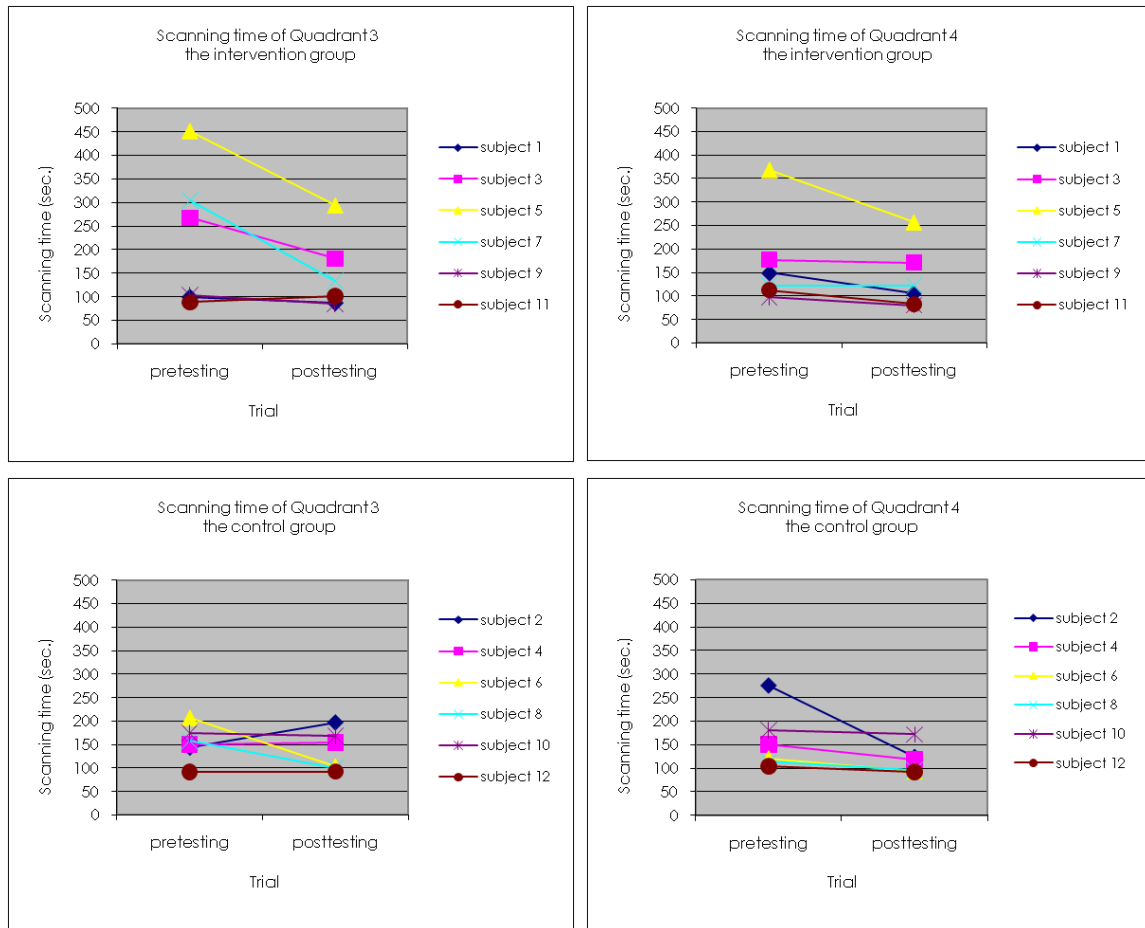


Figure 6 Time of each one-quadrant oral scanning: scanning time of Quadrant 3 for the intervention group (top left); scanning time of Quadrant 4 for the intervention group (top right); scanning time of Quadrant 3 for the control group (bottom left); scanning time of Quadrant 4 for the control group (bottom right).

Table 1 Pretesting results of the average one-quadrant oral scanning time for the intervention group and the control group

	Mean $\pm$ SD		P-value
	Intervention group	Control group	
Average one-quadrant oral scanning time in pretesting (sec.)	195.18 $\pm$ 118.56	155.95 $\pm$ 37.96	0.46

The results for the decrease in task time for one-quadrant oral scanning are shown in Table 2. The average decrease of one-quadrant oral scanning time for the intervention group is 18.81% (SD 10.23%) and 15.04% (SD 13.25%) for the control group. Again the t-test result showed no significant difference between the two groups in terms of decrease of oral scanning time ($P=0.43$). Thus we failed to reject the null hypothesis. Therefore there was not sufficient evidence to conclude that there was a significant decrease in task time for one-quadrant oral scanning as a result of the training on the SIMENDO dental training simulator.

Table 2 Results of the average decrease of one-quadrant oral scanning time for the intervention group and the control group

	Mean $\pm$ SD		P-value
	Intervention group	Control group	
Average one-quadrant oral scanning time in pretesting (sec.)	195.18 $\pm$ 118.56	155.95 $\pm$ 37.96	0.46
Average one-quadrant oral scanning time in posttesting (sec.)	141.73 $\pm$ 73.73	125.89 $\pm$ 34.39	0.64
Average decrease of one-quadrant oral scanning time (%)	18.81 $\pm$ 10.23	15.04 $\pm$ 13.25	0.43

2.4 Discussion

This part of our research was intended to examine whether skills acquired from oral scanning training on a virtual reality simulator could be transferred to the task on a real scanner. The statistical analysis showed that there was no significant change in oral scanning time due to the simulator training. However, if we look into Figure 6, we may notice that the shortening of oral scanning time was more obvious with subjects who took longer time in their first trial. This finding indicates that the SIMENDO simulator may be more effective in training the people with a relatively lower level of eye-hand coordination. Of course, more research concerning this topic should be carried out to test this assumption.

With regard to the validity of performance assessment, it depends strongly on objectivity and standardization of the method being used. In this study several measures were taken to improve these two aspects. One example is the agreement concerning the criteria of a qualified one-quadrant oral scanning established between two investigators. In addition, each oral scanning result was video-recorded for peer double review afterwards. However, a computer-based assessment with its high objectivity and standardization would still be recommended for future studies.

Although the pretesting results showed no significant difference between two groups, we still noticed some subjects performed much worse than the rest, which resulted in the big standard deviation shown in Table 2, especially for the intervention group. Difference among the subjects, if not dealt with properly, might threaten the randomization. Thus, we recommend that a basic task within the SIMENDO simulator can be used as a pre-selecting test to exclude the subjects who may have obviously poor hand-eye coordination.

Another dimension that can be added to future studies is concerning the training session. In this study, we selected 'plane scanning' and 'side scanning' tasks for the training session as subjects from the pilot study reflected that these two were the most essential tasks for the mastery of oral scanning while relatively easier for the non-experienced to start with. But can these two tasks represent the whole training program incorporated in the SIMENDO simulator? It needs to be further validated. Assuming 'plane scanning' and 'side scanning' tasks are validated to represent the SIMENDO simulator training program, how many practices of those two tasks are required to make effect? In this study, we assumed 5 repetitions of each task were required to make effect. Such an assumption was based on the fact that in the pilot study most subjects managed to pass the level we set for the training session, which was

each subject had to pass the 'plane scanning' test and 'side scanning' test incorporated in the SIMENDO simulator twice, within 5 practices. However, we think an assessment of the learning curve for the SIMENDO simulator, which was missing prior to this study, should be conducted for future studies.

Last but not least, the feedback from the subjects involved in this study might also point out some directions for future studies. Some subjects were doubtful about the similarity between the SIMENDO simulator and the 3M Lava™ oral scanner (or the fidelity of the SIMENDO simulator). They commented that "within the SIMENDO simulator there is a fixed point around which I move the scanner, while such a fixed point doesn't exist in a real scanner and thus I can move the real scanner more easily". Therefore, the fidelity level of the SIMENDO simulator should be further studied.

Part II

3 Research methodology

3.1 Introduction

The main question formulated for this research is:

How can communication contribute to increase the probability of academia-industry collaborative research projects success – based on the case study of the ACTA-DelltaTech collaborative research project?

In Part II we intend to answer the following sub-questions:

2. What are the key factors of academia-industry collaborative research project success?
3. How is the ACTA-DelltaTech collaborative research project with regard to those key factors?
4. How can communication contribute to increase the probability of academia-industry collaborative research projects success?

'Literature review' (§3.2) is identified as the research method for sub-question 2 while 'case study' (§3.3) for sub-question 3. For sub-question 4, we follow a 'six-staged communication planning' approach (§3.4). A brief introduction of each method together with the argumentation why each method is appropriate regarding its sub-question is also presented in its responding section.

3.2 Systematic literature review

With sub-question 2:

2. What are the key factors of academia-industry collaborative research project success?

We do not intend to elaborate on or explore new factors of academia-industry collaboration success, but rather to focus on the factors that are insistently identified in the published literature. The study of sub-question 2 starts out from a systematic literature search. Published studies concerning the key factors of academia-industry collaboration success which meet the predefined criteria are selected for further review. Next a comparative study of those selected studies is conducted to identify the key factors for further framework development. The elaborate systematic literature review method is explained in Chapter 4.

3.3 Case study

With sub-question 3:

3. How is the ACTA-DelltaTech collaborative research project with regard to those key factors?

We aim to evaluate the ACTA-DelltaTech collaborative research project from the collaboration point of view.

Yin (2009) stated that what distinguished different research methods were three important conditions: (1) the type of research question posed; (2) the extent of control an investigator has over actual behavior events; and (3) the degree of focus on contemporary as opposed to historical events. We use these three conditions to help us identify the appropriate method to study sub-question 3. Firstly, sub-question 3 is a form of 'how' question, which is more explanatory. Secondly, the ACTA-DelltaTech collaborative research project is closed, which allows no control over or access to the case. Last but not least, the investigator of this study participated and played a key role in the ACTA-DelltaTech collaboration, which gives the possibility of collecting evidence from participant observation. Following Yin's approach of identifying the research method, we conclude that the case study is the appropriate research method to study sub-question 3. A graphic overview of the case study method is presented in Figure 7.

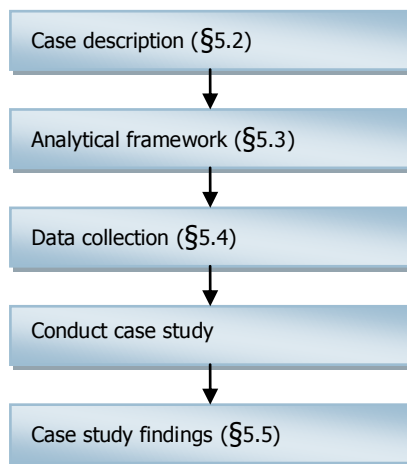


Figure 7 Graphic overview of the case study method

3.4 Communication planning

With sub-question 4:

4. How can communication contribute to increase the probability of academia-industry collaborative research projects success?

We aim to give recommendations on a more effective management of academia-industry collaborative research projects by setting up a strategic communication plan for the project teams. Communication planning is a means which can help us design a communication plan in a systematic way (Vos, 2003). By logically following stages, we can get well thought-out solutions. A graphic overview of the six-staged communication planning method (Vos, 2003) is presented in Figure 8.

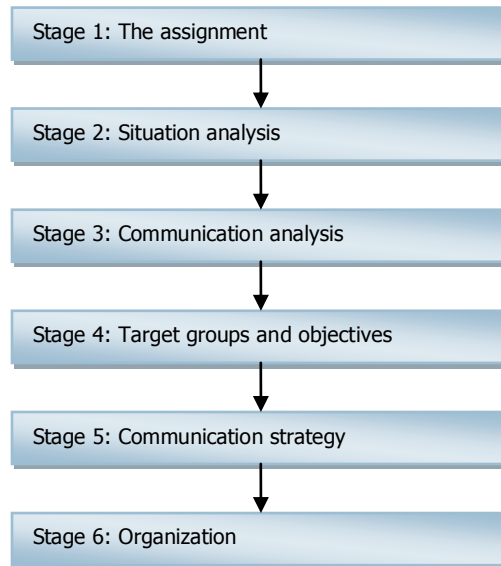


Figure 8 Graphic overview of the six-staged communication planning method

3.5 Conclusion

In this chapter we identified 'systematic literature review', 'case study' and 'communication planning' as the appropriate research methods to study sub-question 2, 3 & 4. In the following chapters, these methods are further explained.

4 Towards a framework for the key factors of academia-industry collaborative research projects success

4.1 Introduction

With sub-question 2,

2. What are the key factors of academia-industry collaborative research projects success?

We aim to understand more about the success (failure) of academia-industry collaborative research projects. Although extensive empirical studies have been done concerning academia-industry collaboration (Barnes et al., 2002; Mora et al., 2004; Butcher & Jeffrey, 2007; Mitev & Venters, 2009; Bjerregaard, 2010; Corley et al., 2006), there is a lack of integration regarding the factors (i.e. 'partners' reputation', 'commitment', 'trust', etc.), dimensions (i.e. 'individual', 'organizational', etc.) and measures employed (i.e. 'survey', 'interview', etc.). Therefore, in this chapter we not only identify the key factors of academia-industry collaborative research projects success but also try to construct a framework for those identified key factors.

In the following sections we start out from a systematic literature search (§4.2) to obtain literature concerning sub-question 2. In §4.3, a literature review with the comparison of selected literature is conducted to identify the key factors. In §4.4, a two-dimensional (2D) structure to evaluate the collaboration is constructed, in which one dimension is macro – micro and the other intra – inter. Then those key factors identified in §4.3 are located in this 2D structure. At the end of this chapter we present the complete framework for the key factors of academia-industry collaborative research projects success.

4.2 Literature search

To find out which existing studies are appropriate to review regarding sub-question 2,

2. What are the key factors of academia-industry collaborative research projects success?

A systematic literature search is conducted within both consolidated literature⁴ and unconsolidated literature⁵, which comprises 3 phases: 1) general searching; 2) specific searching; 3) screening.

PHASE 1 GENERAL SEARCHING

This phase is intended to search for studies that are broadly concerned with 'inter-institutional collaboration' and 'academia-industry' in particular. The general searching is aimed to generate more keywords regarding the topic by introducing similar keywords used in references. 'Science Direct' and 'Web of Knowledge' are selected as appropriate databases, since both of them are leading academic databases offering large quantity of journal articles in diverse disciplines. Since we find that sufficient results could be obtained with the time period set after the year 1995, the search is limited to the time period after the year 1995. In the end, extra keywords obtained from the general searching along with the starting keywords and those derived from sub-question 2 form the pool of keywords (Figure 9). Then all the keywords are categorized into 3 groups (Table 3).

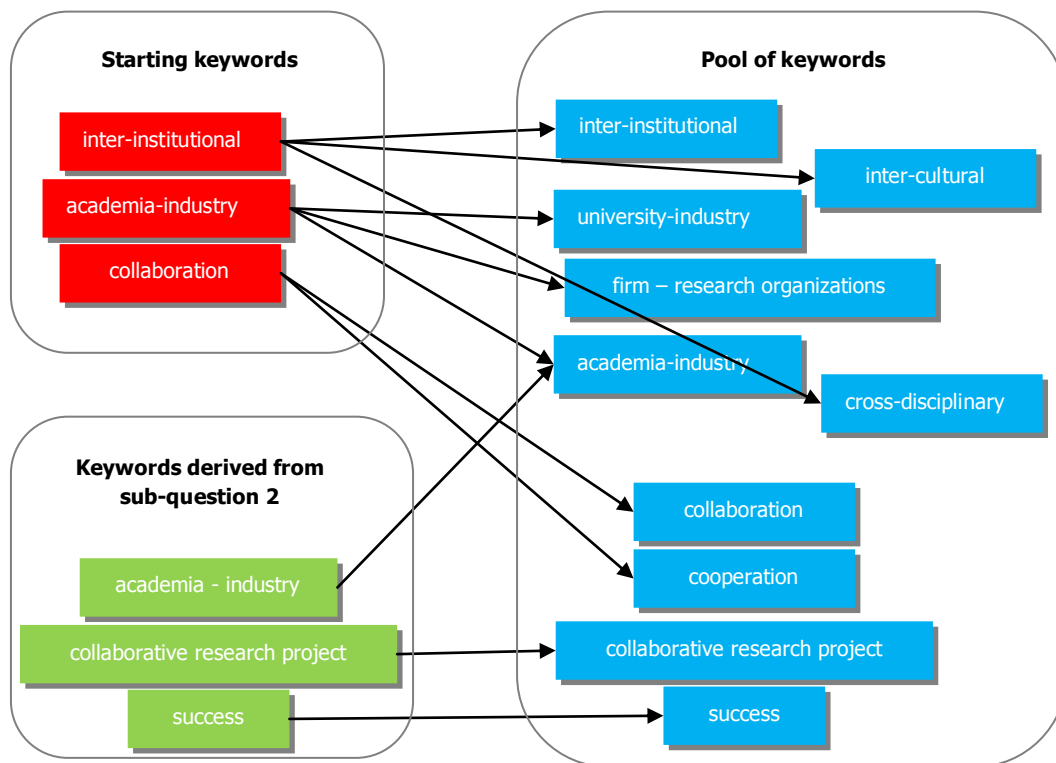


Figure 9 Formation of the pool of keywords. Extra keywords in the pool, which are 'inter-cultural', 'university-industry', 'firm-research organizations', 'cross-disciplinary' & 'cooperation', are obtained from the general searching.

⁴ Consolidated literature includes textbooks and handbooks.

⁵ Unconsolidated literature includes articles in scientific journals.

Table 3 Keywords categorized into 3 groups

Group 1	Group 2	Group 3
inter-institutional	collaboration	success
inter-cultural	collaborative research project	
university - industry	cooperation	
firm AND research organization		
academia - industry		
cross-disciplinary		

PHASE 2 SPECIFIC SEARCHING

This phase aims to search for studies which may provide the answers to sub-question 2. Keywords in the pool are strategically combined to form search strings for the specific searching. A search string that includes keywords from three groups is considered 'highly relevant', while 'relevant' for a search string with keywords from two groups and 'less relevant' for that with a keyword from only one group. The databases and time period used for search in this phase are the same as those in general searching.

PHASE 3 SCREENING

The results of each search string are assessed on screen with predefined criteria as follows:

- The paper is written in English;
- The full-text of the paper is accessible;
- The study identifies (determines) factors that influence the success of academia-industry collaborative research projects;
- The study targets at academia-industry collaboration;
- The study provides empirical evidence.

And a further examination by abstract and full-text is also conducted to refine the results.

Table 4 Numbers of consolidated literature references for each search string at the end of specific searching phase and screening phase. For the consolidated literature search, screening procedure is only conducted for the 'highly relevant' and 'relevant' search strings and skipped for the 'less relevant'.

Nr.	Relevance	Search string	TU Delft Library		Utrecht University Library	
			Searching results	Screening results	Searching results	Screening results
1	+++	inter-institutional AND collaboration AND success	0	0	0	0
2	+++	inter-institutional AND collaborative research project AND success	0	0	0	0
3	+++	inter-institutional AND cooperation AND success	0	0	0	0
4	+++	inter-cultural AND collaboration AND success	0	0	0	0
5	+++	inter-cultural AND collaborative research project AND success	0	0	0	0
6	+++	inter-cultural AND cooperation AND success	0	0	0	0
7	+++	university-industry AND collaboration AND success	0	0	0	0
8	+++	university-industry AND collaborative research project	0	0	0	0

9	+++	AND success university-industry AND cooperation AND success	0	0	0	0
10	+++	firm-research organization AND collaboration AND success	0	0	0	0
11	+++	firm-research organization AND collaborative research project AND success	0	0	0	0
12	+++	firm-research organization AND cooperation AND success	0	0	0	0
13	+++	academia-industry AND collaboration AND success	0	0	0	0
14	+++	academia-industry AND collaborative research project AND success	0	0	0	0
15	+++	academia-industry AND cooperation AND success	0	0	0	0
16	+++	cross disciplinary AND collaboration AND success	0	0	0	0
17	+++	cross disciplinary AND collaborative research project AND success	0	0	0	0
18	+++	cross disciplinary AND cooperation AND success	0	0	0	0
19	++	inter-institutional AND collaboration	0	0	0	0
20	++	inter-institutional AND collaborative research project	0	0	0	0
21	++	inter-institutional AND cooperation	2	0	1	0
22	++	inter-cultural AND collaboration	1	0	0	0
23	++	inter-cultural AND collaborative research project	0	0	0	0
24	++	inter-cultural AND cooperation	0	0	0	0
25	++	university-industry AND collaboration	10	0	1	0
26	++	university-industry AND collaborative research project	2	0	0	0
27	++	university-industry AND cooperation	10	0	17	0
28	++	firm-research organization AND collaboration	0	0	1	0
29	++	firm-research organization AND collaborative research project	0	0	0	0
30	++	firm-research organization AND cooperation	0	0	0	0
31	++	academia-industry AND collaboration	2	0	0	0
32	++	academia-industry AND collaborative research project	1	0	0	0
33	++	academia-industry AND cooperation	0	0	0	0
34	++	cross disciplinary AND collaboration	0	0	0	0
35	++	cross disciplinary AND collaborative research project	0	0	0	0
36	++	cross disciplinary AND	0	0	0	0

		cooperation				
37	+	inter-institutional	3	- ⁶	4	-
38	+	academia-industry	11	-	0	-
39	+	inter-cultural	1	-	22	-
40	+	university-industry	131	-	211	-
41	+	firm-research organization	3	-	1	-
42	+	cross-disciplinary	15	-	23	-
43	+	collaboration	235	-	457	-
44	+	collaborative research project	9	-	11	-
45	+	cooperation	852	-	3500	-

Table 5 Numbers of unconsolidated literature references for each search string at the end of specific searching phase and screening phase. For the unconsolidated literature search, screening procedure is only conducted for the 'highly relevant' search strings and skipped for the other strings.

Nr.	Relevance	Search string	Science Direct		Web of Knowledge	
			Searching results	Screening results	Searching results	Screening results
1	+++	inter-institutional AND collaboration AND success	30	1	4	1
2	+++	inter-institutional AND collaborative research project AND success	5	1	0	0
3	+++	inter-institutional AND cooperation AND success	19	0	5	0
4	+++	inter-cultural AND collaboration AND success	24	2	1	0
5	+++	inter-cultural AND collaborative research project AND success	7	2	0	0
6	+++	inter-cultural AND cooperation AND success	17	0	0	0
7	+++	university-industry AND collaboration AND success	73	2	43	3
8	+++	university-industry AND collaborative research project AND success	13	2	3	0
9	+++	university-industry AND cooperation AND success	50	0	40	2
10	+++	firm-research organization AND collaboration AND success	25	1	5	0
11	+++	firm-research organization AND collaborative research project AND success	0	0	2	0
12	+++	firm-research organization AND cooperation AND success	24	1	8	0
13	+++	academia-industry AND collaboration AND success	21	2	23	1
14	+++	academia-industry AND collaborative research project AND success	3	2	2	0
15	+++	academia-industry AND cooperation AND success	7	0	16	0
16	+++	cross disciplinary AND collaboration AND success	16	1	17	0
17	+++	cross disciplinary AND collaborative research project AND success	2	0	2	0
18	+++	cross disciplinary AND cooperation AND success	3	0	1	0

⁶ '-' refers to the skipping of screening procedure.

19	++	inter-institutional AND collaboration	51	-	65	-
20	++	inter-institutional AND collaborative research project	6	-	3	-
21	++	inter-institutional AND cooperation	36	-	37	-
22	++	inter-cultural AND collaboration	46	-	12	-
23	++	inter-cultural AND collaborative research project	10	-	1	-
24	++	inter-cultural AND cooperation	34	-	4	-
25	++	university-industry AND collaboration	130	-	199	-
26	++	university-industry AND collaborative research project	21	-	5	-
27	++	university-industry AND cooperation	95	-	117	-
28	++	firm-research organization AND collaboration	29	-	63	-
29	++	firm-research organization AND collaborative research project	2	-	7	-
30	++	firm-research organization AND cooperation	29	-	83	-
31	++	academia-industry AND collaboration	47	-	48	-
32	++	academia-industry AND collaborative research project	4	-	1	-
33	++	academia-industry AND cooperation	20	-	15	-
34	++	cross disciplinary AND collaboration	29	-	199	-
35	++	cross disciplinary AND collaborative research project	4	-	18	-
36	++	cross disciplinary AND cooperation	6	-	41	-
37	+	inter-institutional	861	-	399	-
38	+	academia-industry	530	-	274	-
39	+	inter-cultural	92,848	-	214	-
40	+	university-industry	379,420	-	896	-
41	+	firm-research organization	60,017	-	1,525	-
42	+	cross-disciplinary	12,123	-	1,964	-
43	+	collaboration	177,092	-	72,957	-
44	+	collaborative research project	49,820	-	3,053	-
45	+	cooperation	167,346	-	100,000	-

4.3 Literature review

The removal of duplicate references leaves five studies for further review, which are listed as follows:

1. Barnes, T.A., Pashby, I.R. & Gibbons, A.M. (2002), "Effective university-industry interaction: a multi-case evaluation of collaborative R&D projects", *European Management Journal*, Vol. 20, No. 3, pp. 272-285;
2. Mora, E.M., Montoro, M.A. & Guerras, L.A. (2004), "Determining factors in the success of R&D cooperative agreements between firms and research organizations", *Research Policy*, Vol. 33, pp. 17-40;
3. Butcher, J. & Jeffrey, P. (2007), "A view from the coal face: UK research student perceptions of successful and unsuccessful collaborative projects", *Research Policy*, Vol. 36, pp. 1239-1250;
4. Bjerregaard, T. (2010), "Industry and academia in convergence: micro-institutional dimensions of R&D collaboration", *Technovation*, Vol. 30, pp. 100-108;
5. Bernardos, A.M. & Casar, J.R. (2009), "Critical factors for success in university-industry research projects", *Technology Analysis & Strategic Management*, Vol. 21, No. 5, pp. 599-616

Those five studies are the unconsolidated literature results of 'highly relevant' search strings. All of them are intended to investigate the factors associated with the success of academia-industry collaboration starting out from a theoretical basis. The theoretical outcomes are further validated with empirical evidence provided by either interviews or surveys. Therefore, we think these studies are appropriate for the further review.

We intend to review the five studies with the focus on the key factors of academia-industry collaborative research projects success. First, factors associated with the success of collaborative research projects which emerge from each individual study are tabulated together in order that common factors can be identified (Table 6). Any factor which is identified as the factor of collaboration success in more than one study is considered as a key factor with great significance. This comparative study is used as a means of identifying key factors of collaboration success. Some common themes emerge from the factors and we name the themes according to Barnes's (2002) study. The final list of key factors of collaboration success is presented in Table 7, along with the influence direction of each factor on collaboration success indicated in those studies.

Table 6 Success factors of collaborative research projects identified in each individual study. All the factors from the five studies are first tabulated together. Then the factor which is identified in more than one study is identified as the key factor of success.

Common themes	Study 1 Barnes et al (2002)	Study 2 Mora et al (2004)	Study 3 Butcher et al (2007)	Study 4 Bjerregaard (2010)	Study 5 Bernardos et al (2009)
Partners	Complementary expertise		Complementary expertise		
	Past collaboration partners	Past collaboration partners	Past collaboration partners		
	Collaborative experience	Collaborative experience			Collaborative experience
	Shared vision				
	Complementary aims				
	No hidden agendas				
		Partners' reputation			
		Understanding			Understanding
		Enthusiasm			
					Company's interest in assimilating the results
					Qualified professionals
					Ease of access to company information
Communication	Communication frequency	Communication frequency	Communication frequency		
Project management	Clearly defined objectives	Clearly defined objectives			
	Clearly defined responsibilities	Clearly defined responsibilities			
	Mutually agreed project plan		Mutually agreed project plan		

	Realistic aims		Realistic aims
	Adequate resources		Adequate resources
	Defined project milestones		
	Regular progress monitoring		Regular progress monitoring
	Ensuring collaborators deliver	Ensuring collaborators deliver	
	Good project manager		
			Project usefulness
Environmental factors	Corporate stability		
Ensuring equality	Mutual benefit		
	Equality of contribution		
Cultural gap	Cultural gap between academia and industry		Cultural gap between academia and industry
Universal success factors	Mutual trust	Mutual trust	Mutual trust
	Commitment	Commitment	
	Continuity	Continuity	
	Teamwork		
		Conflict	
		Dependence	
			Confidence
			Coordination

Table 7 Key factors of collaborative research projects success identified through a comparative study, with their direction of influence on collaboration success

Common themes	Key factors	Direction of influence on collaboration success
Partners	Complementary expertise	Complementary expertise promotes success.
	Past collaboration partners	Past collaborative experience between partners promotes success.
	Collaborative experience	Prior collaborative experience acquired by each partner promotes success.
	Understanding	Greater understanding of the collaborative project promotes success.
Communication	Communication frequency	More frequent communication promotes success.
Project management	Clearly defined objectives	Clearly defined objectives promote success.
	Clearly defined responsibilities	Clearly defined responsibilities promote success.
	Mutually agreed project plan	Mutually agreed project plan promotes success.
	Realistic aims	Realistic aims promote success.
	Adequate resources	Adequate resources promote success.
	Regular progress monitoring	Regular progress monitoring promotes success.
	Ensuring collaborators deliver	Ensuring collaborators deliver promotes success.
Cultural gap	Cultural gap between academia and industry	It depends on the situation.
Universal success factors	Mutual trust	A high level of mutual trust promotes success.
	Commitment	More commitment between partners promotes success.
	Continuity	Prospects of continuity promote success.

4.4 Framework development

Academia-industry collaboration projects are more than just universities and firms come together to work. Regarding the potentially different institutional logics and norms, different organizational structures and management types as well as diverse collaboration modes, it is perhaps understandable that no single perspective is fully able to capture the entire picture of academia-industry collaboration. A typical academia-industry collaborative research project usually involves two organizations, the industrial company and its academic partner. Each organization assigns its research student(s) to collaborate on the research and its supervisor to jointly supervise the research ongoing. With regard to such a collaboration mode, we think at least two angles can be used to approach a typical academia-industry collaboration practice. One angle is the organizational level vs. the individual level. The other angle is the inter-relation vs. intra-relation.

Our study does not intend to elaborate on all the angles we can use to explore the phenomenon of academia-industry collaboration, but rather to build a structure which can help delineate those key factors identified in §4.3 in an academia-industry collaboration practice. The two angles are applied to build a two-dimensional structure, with which we can understand the context of each key factor in an academia-industry collaboration practice. To locate each key factor in the 2D structure (Figure 10), we ask the following questions:

1. Is this factor applied to individual level, organizational level, or both levels?
2. Does this factor happen between organizations (individuals) or within one organization (individual)?

Table 8 Questions that help identify the domain for each factor in the 2D structure

	Question 1	Question 2	Domain
Case 1	organizational	within organization	macro – intra
Case 2	organizational	between organizations	macro – inter
Case 3	individual	within individual	micro – intra
Case 4	individual	between individuals	micro - inter

In Figure 10 we notice that some factors can be both organization-related and individual-related, i.e. 'mutual trust', 'commitment', 'complementary expertise', 'past collaboration partners', 'collaborative experience' and 'understanding'. In Figure 10 we also notice that factors under the theme 'project management' are cross two domains. Such an arrangement reflects the fact that 'project management' usually involves the interaction between organizations and individuals.

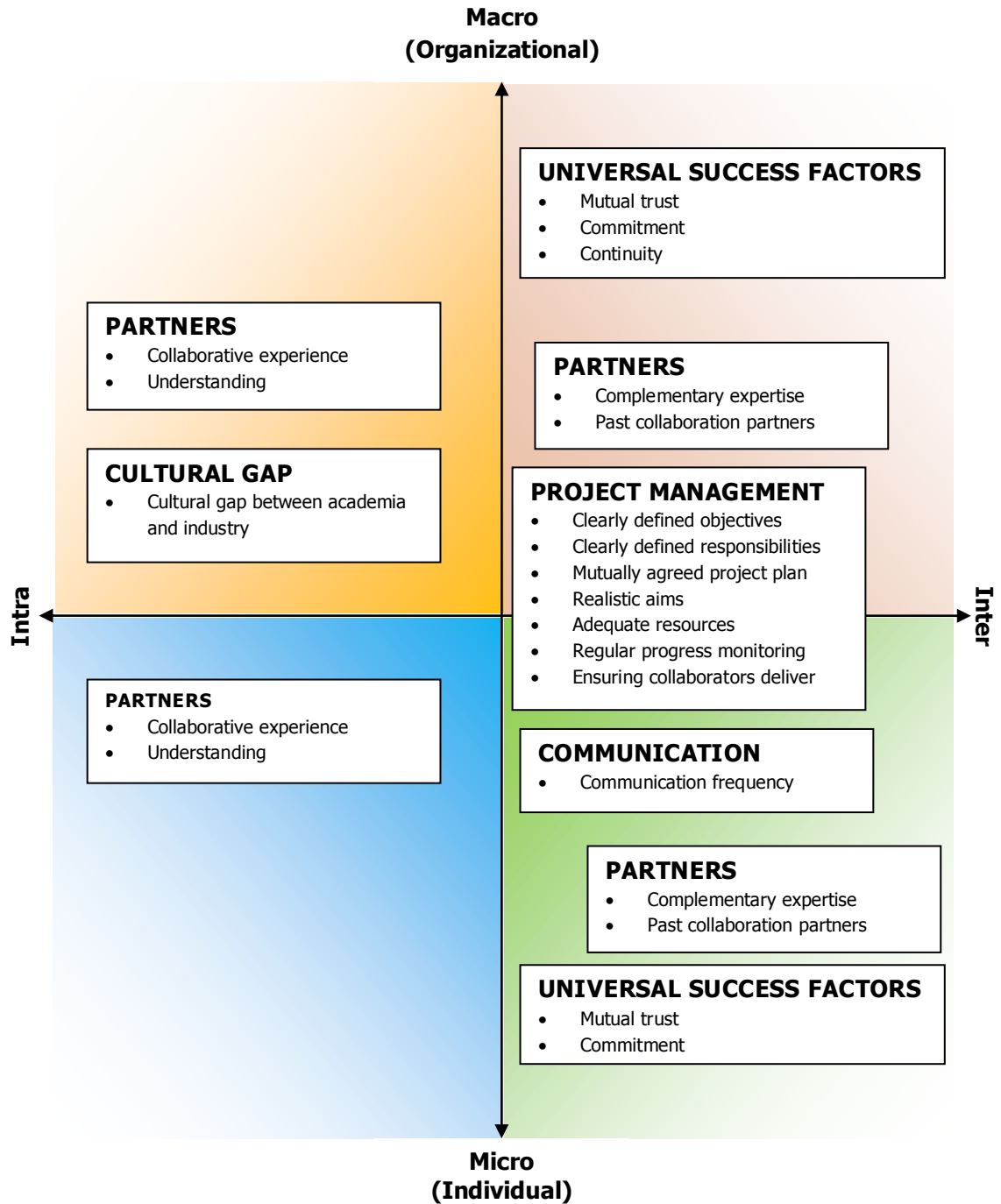


Figure 10 Framework for the key factors of academia-industry collaborative research projects success. Each factor is located in the two-dimensional structure according to its macro-micro, inter-intra proposition.

4.5 Conclusion

In this chapter we developed a framework for the key factors of academia-industry collaborative research projects success. We started out from identifying those key factors by means of a comparative study of selected literature. From this starting point we built a two-dimensional structure and located each key factor in it. In Chapter 5 this framework will be further adapted and operationalized towards the ACTA-DelltaTech collaboration case we intend to evaluate.

5 Case study: ACTA-DelltaTech collaborative research project

5.1 Introduction

In Chapter 4 we developed a framework for the key factors of academia-industry collaborative research projects success. That framework gives us insights into the success (failure) of academia-industry collaboration. In this chapter, we apply the knowledge we gained in Chapter 4 to answer sub-question 3:

3. How is the ACTA-DelltaTech collaborative research project with regard to those key factors?

The evaluation of the ACTA-DelltaTech collaboration follows the case study method. We start with a short description of the ACTA-DelltaTech collaborative research project (§5.2). In §5.3, we present an analytical framework adapted towards the ACTA-DelltaTech case and data collection method is explained in §5.4. Case study findings are finally presented in §5.5.

5.2 Case description

PARTNER'S PROFILE – ACTA

The Academic Centre for Dentistry Amsterdam (ACTA) conducts scientific research, teaches and provides patient care in the field of dentistry. It has a staff of 500 and a student body of 900. With a student intake of 125, ACTA is one of the biggest dentistry education & training programs in the world.

PARTNER'S PROFILE – DELLTATECH

DelltaTech was founded in 2002 as a Dutch entity and is specialized in developing and distributing computerized training products in the medical field. DelltaTech produces medical training devices and software.

SIMENDO DENTAL TRAINING SIMULATOR

SIMENDO dental training simulator was developed by DelltaTech. It is a model that simulates the 3M Lava™ Chairside Oral Scanner and designed to train eye-hand coordination skills using abstract tasks such as camera navigation and basic scanning such as plane scanning and side scanning.

ACTA-DELLTATECH COLLABORATIVE RESEARCH PROJECT

- Initiation

ACTA is one of the first users of the new 3M Lava™ Chairside Oral Scanner. The required hand-eye coordination to efficiently move the scanner over the patient's

teeth is cumbersome and requires training. For this purpose, earlier ACTA asked DelltaTech to develop a training simulator which can be incorporated into a dental curriculum. Once DelltaTech finished the prototype of the simulator, a research under the collaboration between ACTA and DelltaTech was initiated to validate the training effectiveness of the simulator. As DelltaTech's client and collaborative research partner, ACTA would decide whether or not to further invest in the simulator development based on the research result.

- Collaboration

ACTA and DelltaTech each assigned a research student for the project. The student who represented ACTA is a 5th year student from ACTA with a specialization in dentistry. The other student who represented DelltaTech is a 2nd year master student from TU Delft with a partial specialization in Biomedical Engineering. To both students, this project was a major part of their graduation project. ACTA and DelltaTech also each assigned a supervisor to guide its own students through the whole project.

- Outcome

At the end of this collaborative project, the research failed to prove the training effectiveness of the SIMENDO simulator. ACTA claimed that they decided not to further invest in the simulator development with regard to that research result. However, DelltaTech insisted that they were not satisfied with the research project in collaboration with ACTA with arguments including but not limited to:

- The expectations of different stakeholders on this collaboration were not well managed;
- The project progress was not regularly updated to each partner.

DelltaTech's dissatisfaction of that collaborative research project initiated an evaluation of that collaboration practice and a study of how to increase the probability of academia-industry collaborative research projects success.

5.3 Analytical framework

Before we apply the framework for the key factors of academia-industry collaborative research projects success, which is referred to as 'theoretical framework' below to distinguish from the analytical framework we intend to develop in this section, to evaluate the ACTA-DelltaTech collaboration, some adaption must be made. That is because each case that occurs in real life has its specific context and conditions, which are not addressed in the theoretical framework. Regarding the case description presented in §5.2, we make the following adaption:

1. Focus on the micro (individual) domain.

As described in §5.2, ACTA and DelltaTech each assigned a research student to conduct the research and a supervisor to guide its own student. Organization-related factors were not obviously reflected in the collaboration since the collaboration activities mainly happened among those four participants. Thus, the evaluation of the ACTA-DelltaTech case focuses on the micro (individual) domain of the theoretical framework.

2. Differentiate individuals.

As stated before, the key participants in the ACTA-DelltaTech collaboration were two research students and their supervisors. They fulfilled different functions in that project. Thus, we think it necessary to differentiate those two types of individuals in the analytical framework.

3. Reflect 'cultural gap' in the individual domain.

We stated before that organization-related factors were not obviously reflected in the ACTA-DelltaTech collaboration. However, we can not deny the fact that those two supervisors, who represented each organization, might subconsciously bring their own institutional culture into their expectation, supervision and management of the project. Therefore, we think the factor 'cultural gap between academia and industry' should be remained for the analytical framework, although it is a factor that belongs to the organizational domain.

With these adaption made based on the theoretical framework constructed in Chapter 4, a complete analytical framework developed to evaluate the ACTA-DelltaTech collaboration is presented in Figure 11.

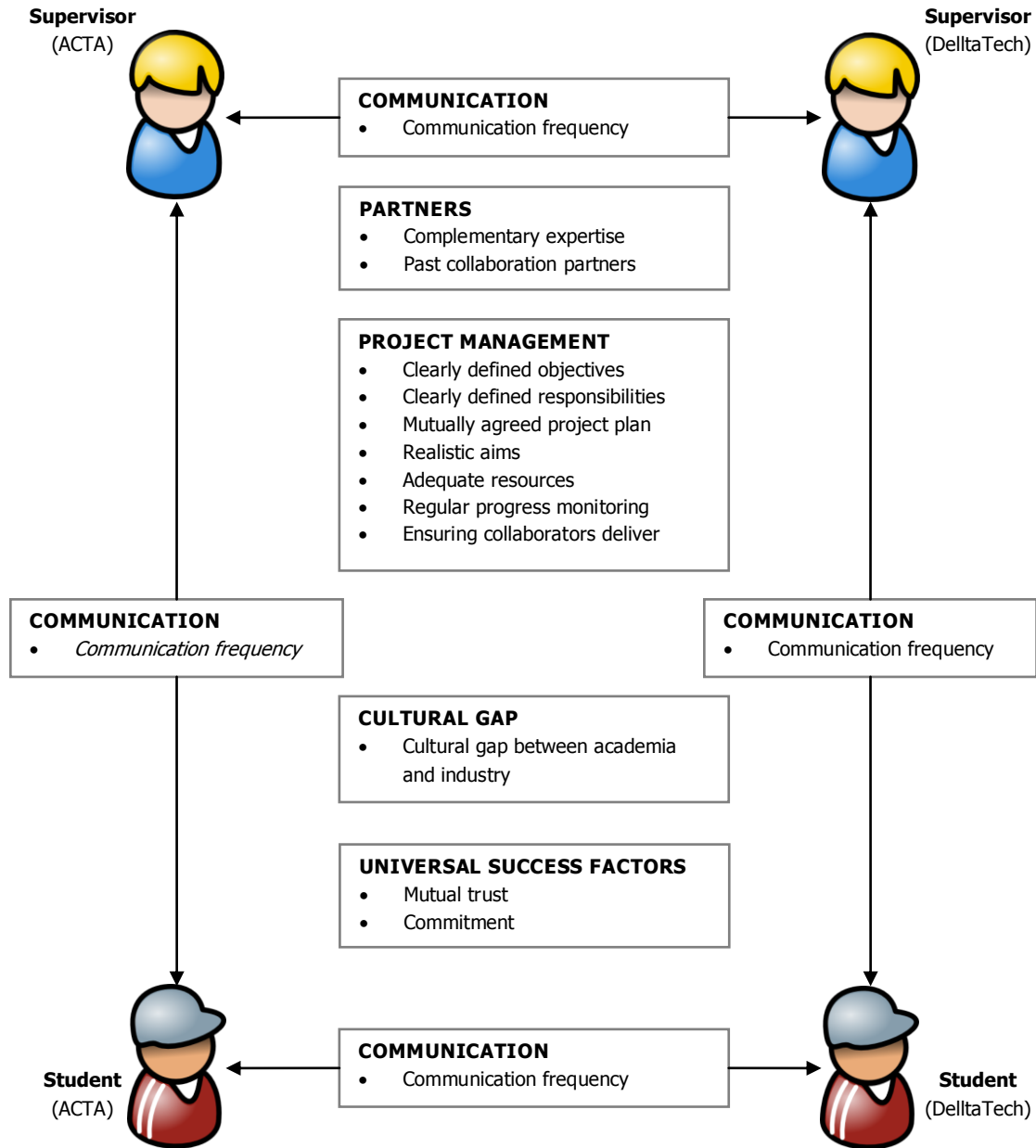


Figure 11 Analytical framework which guides the investigation into the ACTA-DeltaTech collaboration

5.4 Data collection

To evaluate the ACTA-DeltaTech collaboration with the analytical framework developed in §5.3, we need to collect information (or evidence) of that collaboration case with regard to all the factors listed in the analytical framework. The most commonly used source of evidence in doing case studies are 'documentation', 'archival records', 'interviews', 'direct observation', 'participant observation' and 'physical artifacts' (Yin, 2009). In the case study of the ACTA-

DelltaTech project, we think three sources of evidence are relevant: 'documentation', 'interviews' and 'participant observation'. However, our request to interview the two supervisors and the research student from ACTA is declined. As explained before, the research student who represented DelltaTech to participate in the ACTA-DelltaTech project is the same as the investigator of this study, we think the 'participant observation' and 'documentation' as sources of evidence is accessible.

Anticipating the data collection methods we might use, which are participant observation and documentation, we first develop each factor into a question, which can guide the evidence collection, regardless of the collection method.

Table 9 Questions developed for the key success factors in the analytical framework with identified source of evidence

Common themes	Key factors	Questions	Source of evidence
Partners	Complementary expertise	Do you think the expertise and skills of the two partners complement each other in the ACTA-DelltaTech project?	Participant observation
	Past collaboration partners	In the past, have two partners collaborated with each other?	Participant observation
Communication	Communication frequency	How frequent did the participants communicate with each other and how frequent did the joint project meeting take place in the ACTA-DelltaTech project?	Documentation
	Communication content	What was the proportion of each subject in the overall communication in the ACTA-DelltaTech project?	Documentation
Project management	Clearly defined objectives	Were there clearly defined objectives in the ACTA-DelltaTech project?	Participant observation
	Clearly defined responsibilities	Do you think the responsibilities of each participant were clearly defined in the ACTA-DelltaTech project?	Participant observation
	Mutually agreed project plan	Was there a mutually agreed project plan in the ACTA-DelltaTech project?	Participant observation
	Realistic aims	Do you think the aims set for the ACTA-DelltaTech project were realistic and achievable?	Participant observation
	Adequate resources	Do you think the ACTA-DelltaTech project got adequate support in terms of resources from both partner teams? (I.e. equipment, financial support, etc.)	Participant observation
	Regular progress monitoring	Do you think the progress of the ACTA-DelltaTech project was regularly monitored by both supervisors?	Participant observation
	Ensuring collaborators deliver	Do you think there was an agreement on the deliverables between two partners?	Participant observation
Cultural gap	Cultural gap between academia and industry	Did you realize the profit-making logic from the industrial partner or the publishing logic from the academic partner during the ACTA-DelltaTech project?	Participant observation
Universal success factors	Mutual trust	Do you think two partners trust each other's behavior and performance during the ACTA-DelltaTech project?	Participant observation
	Commitment	Do you think two partners were committed to each other during the ACTA-DelltaTech project?	Participant observation

5.5 Case study findings

The case study findings of the ACTA-DelltaTech collaborative research project are each presented under the theme 'partners', 'communication', 'project management', 'cultural gap' and 'universal success factors' in the following sections.

5.5.1 Partners

With regard to 'complementary expertise', student A⁷'s knowledge in dentistry helped with the research introduction and instruction giving. While student D⁸ contributed to the research design and data analysis with her knowledge in research methodology and statistics. Student D thinks that the two research students did complement each other with regard to skills and expertise required to accomplish the project. In terms of 'past collaboration partners', the ACTA-DelltaTech project was the first time for not only the two students but also the two supervisors to assemble a team to carry out a research project.

5.5.2 Communication

As Figure 12 shows, the frequency of communication via emails (39 in total) far outnumbered that via meetings (14 in total) or documents (13 in total). Email was the primary communication means used in the ACTA-DelltaTech project. Figure 12 also indicates that the frequency of communication reached the highest in the 'planning' stage of the project. We also find that except for the 'initiating' stage, there is neither communication in any form between the two supervisors nor joint group meetings.

⁷ Student A refers to the research student who represented ACTA.

⁸ Student D refers to the research student who represented DelltaTech.

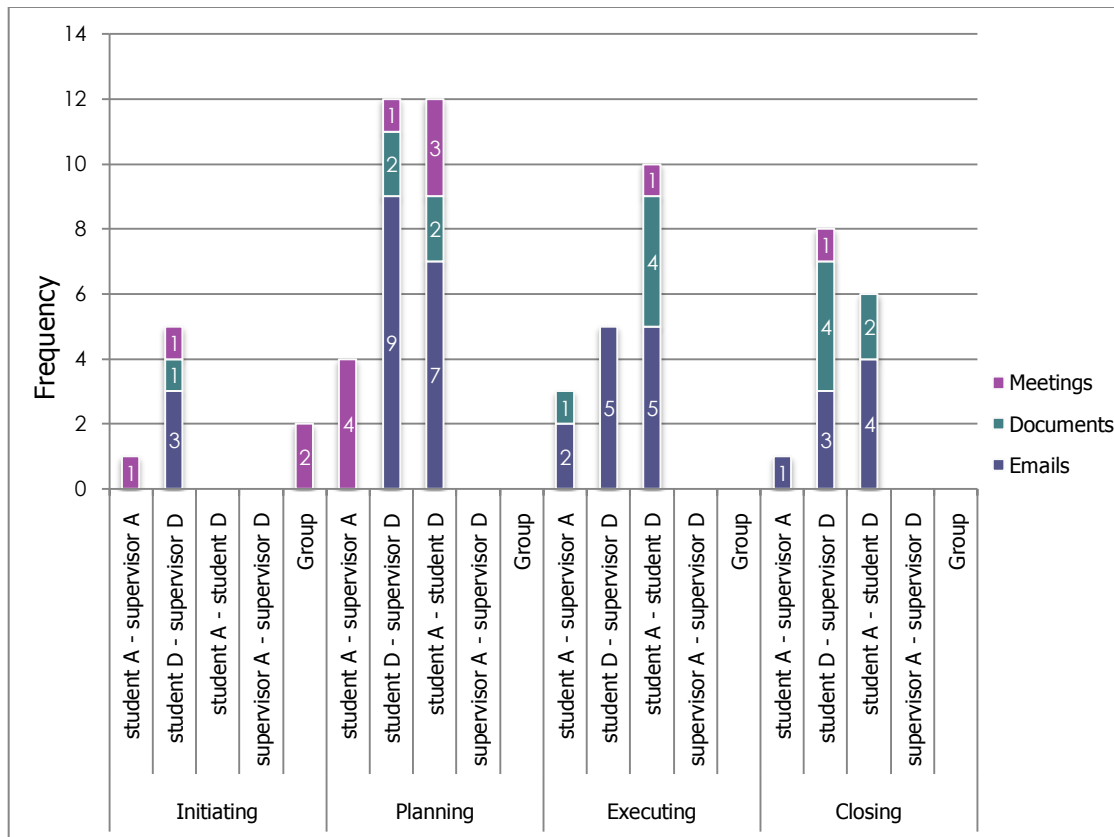


Figure 12 Communication frequency in the ACTA-DelltaTech project

5.5.3 Project management

According to student D, the ACTA-DelltaTech project had 'clearly defined objectives' and a 'mutually agreed project plan'. In addition, the aims set for that project were considered realistic and achievable since they were approved by both supervisors. With regard to 'adequate resources', student D commented that the needs for the devices, test subjects and budget were all satisfied with the support from ACTA and DelltaTech. However, there was a lack of 'clearly defined responsibilities' between two partners. It is also noted that the slow response from one supervisor often led to the change of project progress, which could cause unclear project status. Last but not least, although both partners managed to deliver the output expected by each other, there was no contract to ensure the collaborators deliver in that project.

5.5.4 Cultural gap

According to what student D observed, DelltaTech did expect a positive outcome of the ACTA-DelltaTech collaborative research, which might bring commercial benefit to the company itself. However, its academic partner ACTA did not have a particular expectation on the results and seemed to focus more on the confidentiality of the research itself. Different logics between academia and industry did not cause institutional tensions in the ACTA-DelltaTech project.

5.5.5 Universal success factors

Both partners demonstrated their commitment to the ACTA-DelltaTech project. However, it is noted that no effort was made for trust development between the partners, given the fact that the ACTA-DelltaTech project was the first time for them to collaborate.

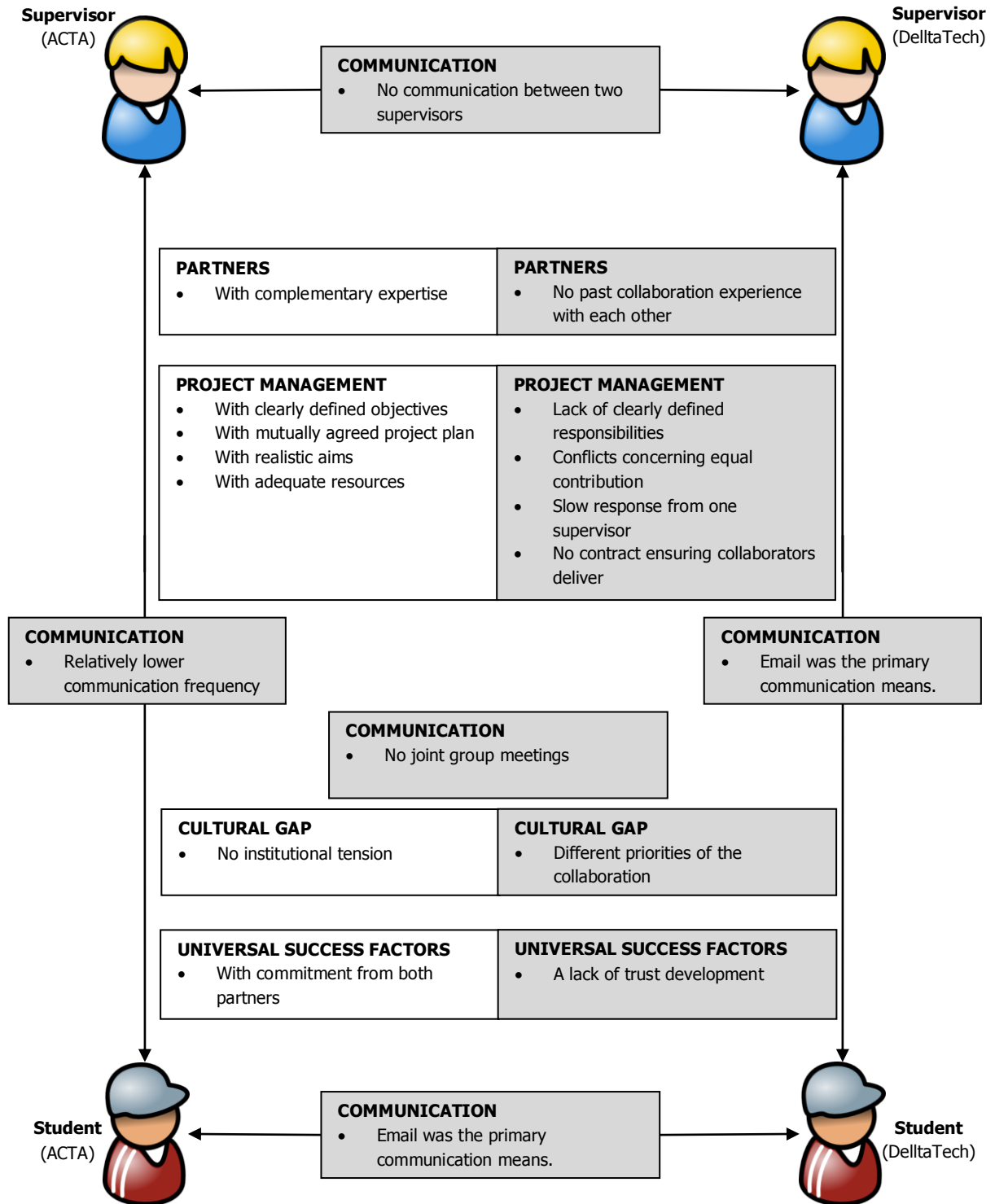


Figure 13 Case study findings which are presented under the theme 'partners', 'communication', 'project management', 'cultural gap' and 'universal success factor'.

5.6 Implications

The case study findings concerning the factor 'past collaboration partners' and 'mutual trust' indicate that two partner teams did not have prior experience of working together. When the ACTA-DelltaTech collaboration project started, no effort was made in trust development among the participants. We think such an ignorance of trust development could impose threats to inter-institutional or interpersonal relationship. Therefore, for a future academia-industry collaborative project, we think trust development should be encouraged between new partners. Furthermore, the development of trust between new partners is facilitated when they have a great degree of one-to-one contact (Barnes, 2002). Therefore, we recommend that situations (formal situations such as meetings or informal situations such as drinks) should be created for trust development between new partners.

The case study findings under the theme 'communication' reveal that Email is the main communication means used in the ACTA-DelltaTech project. However, while the most common way of moving ideas, thoughts, decisions and documents around in today's teams is through Email, it has several shortcomings that make it a poor choice for being the primary platform for team communication (Jackson, 2005), which include but are not limited to:

- No group memory;
- Poor contextualization;
- Poor tool for managing documents.

The problems associated with Email communication can be solved by establishing a platform for the project team which relies on collaboration technologies. This platform can be a project website or intranet board and offers collaboration management tools. Such a platform is intended to not only compensate for the shortcomings of over relying on Email communication but also help facilitate other aspects of a collaborative project.

The case study under the theme 'communication' also finds that there is an apparent lack of supervisor-supervisor communication and joint project meetings in the ACTA-DelltaTech project, which could impede the participants to exchange information and to develop common purposes and concepts about their situation (Van De Ven & Walker, 1984). With regard to this problem, we think 'steering group' meetings should be arranged for the collaboration project. The term 'steering group' is defined as a body consisting of the key representatives from each partner, which meets on a regular basis throughout the collaboration to discuss progress, strategy, direction and issues of policy. There is a tendency in successful collaborative projects to use the 'steering group' meeting (Barnes, 2002). Therefore we recommend that this form of meetings should be arranged for the future academia-industry collaborative project.

With regard to 'project management', the lack of clearly defined responsibilities between two partners could impose risk of unequal contribution as perceived by student D in the ACTA-DelltaTech case. Therefore, a clear definition of responsibilities and roles of each partner, hopefully based on each partner's expertise and capacity, is recommended for the management of future collaborative projects. Regarding the conflicts among the participants, we think a channel should be open for participants to openly and honestly discuss the problem when it arises and find solutions. A lack of contract to ensure collaborators deliver is also noted in the ACTA-DelltaTech project. We think ensuring collaborators deliver is an issue

closely related with the collaboration outcomes. And the collaboration outcomes are important since they are needed to demonstrate the value of collaboration and to justify the partners' investment in the project in terms of time and resource (Barnes, 2002). Given the importance placed on collaboration outcomes, we think a contract should be established which ensures the delivery of expected collaboration outcomes.

Another issue noted in the ACTA-DelltaTech case is the slow response from one supervisor. It could cause trouble to the project executing, since both students had to either wait for the response to go further along the project or take a step back afterwards. This problem could further lead to an unclear project status to participants. To deal with this issue, we think future collaborative projects should include a mechanism which encourages immediate feedback. Besides real time communication technologies (such as Messenger), this goal can also be realized by making clear the closing time for each discussion and sending reminders.

The case study findings concerning the 'cultural gap between academia and industry' indicate different institutional logics between ACTA and DelltaTech. ACTA aimed to run the research project for its research student leading to degree qualification and the publication of research results in academic journals whilst DelltaTech, as a small sized enterprise, cared more about the commercial relevance of the research project. Although no institutional tensions were caused due to that, it could give rise to different priorities of two partners. Therefore, for the future academia-industry collaborative project, we recommend that a contract which ensures mutual benefit between industrial and academic partners is achieved should be established.

Table 10 Implications for more effective management of academia-industry collaborative research projects, which are made based on the case study findings

Common themes	Key factors	Case study findings	Implications
Partners	Past collaboration partners	No past collaboration experience with each other	Trust development and conflict solving mechanism
Universal success factors	Mutual trust	A lack of trust development	
Communication	Communication frequency	Email was the primary communication means.	A platform such as a project website or intranet board
		No joint project meetings	'Steering group' meetings
Project management	Clearly defined responsibilities	Lack of clearly defined responsibilities	A clear definition of roles and responsibilities
		Conflicts concerning equal contribution	A channel for open discussion
	Regular progress monitoring	Slow response from one response	A mechanism which encourages immediate feedback
	Ensuring collaborators deliver	No contracts ensuring collaborators deliver	Establishment of the contract which ensures collaborators deliver
Cultural gap	Cultural gap between academia and industry	Different priorities of the collaboration	Balance and mutual benefit

5.7 Conclusion

In this chapter we evaluated the ACTA-DelltaTech collaborative research project following the case study method. Based on the theoretical framework for the key factors of academia-

industry collaborative research projects success constructed in Chapter 4, we developed an analytical framework for the ACTA-DelltaTech case. Participant observation and documentation were the two main sources of evidence. Case study findings were presented in §5.5 according to the themes. Finally, based on the case study findings, we made implications for more effective management of academia-industry collaborative research projects in §5.6. In the next chapter, these implications are taken into account to set up a strategic communication plan for the academia-industry collaborative research project team.

6 A strategic communication plan for the academia-industry collaborative research project team

6.1 Introduction

The evaluation of the ACTA-DelltaTech collaborative research project from the collaboration point of view offered us some implications for a more effective management of academia-industry collaboration. In this chapter we continue looking into the effective academia-industry collaboration management by answering sub-question 4:

4. How can communication contribute to increase the probability of academia-industry collaborative research projects success?

We follow the 'six-staged communication planning' method to approach this problem and work out a strategic communication plan for the academia-industry collaborative research project team. However, the last stage 'organization' is not discussed in this research as that stage is more relevant to the execution of the communication plan, which is not the focus of our research.

6.2 Design of a strategic communication plan

6.2.1 Stage 1: The assignment

The answer we anticipate for sub-question 4 is a communication plan for the project team. In addition, such a communication plan is specially designed for a typical academia-industry collaborative research project team, which involves research students assigned from each collaborative partner and guided by their supervisors. The pattern of the typical academia-industry collaborative research project team is further explained in §6.2.2. Thus, the assignment we identify first is:

To design a strategic communication plan for academia-industry collaborative research project teams, which follow the typical pattern of this type of teams.

6.2.2 Stage 2: Situation analysis

There are several problems reflected in the evaluation findings of the ACTA-DelltaTech case, which include:

- No past collaboration experience with each other;
- A lack of trust development;
- Email was the primary communication means;
- No joint project meetings;
- Lack of clearly defined responsibilities;
- Conflicts concerning equal contribution;
- Slow response from one supervisor;
- No contracts ensuring collaborators deliver;
- Different priorities of the collaboration.

Of course there must be more than just one cause of these problems. However, we think the lack of a project manager, or someone in the team who played the role to moderate all the information flow, update the project plan and schedule, provide status report and manage communication, could be the main cause. However, it seems that the lack of project manager can be quite typical in a lot of academia-industry collaborative research projects.

Small and medium sized enterprises, like DelltaTech in our case, usually don't have big R&D capacities. Companies within this category usually tend to seek for collaboration with academic institutions to conduct research and development. They also tend to hire students who undertake these research projects for their internship or graduation projects. A typical pattern of this type of collaborative teams comprises two research students, with one assigned by the academic partner and the other assigned by the industrial partner, and two supervisors, with one representing the academic and the other representing the industrial. This type of team is usually newly-assembled for an individual project. Supervisors tend to give more guidance on conducting research rather than manage the project. In most occasions even those supervisors tend to play the role of project manager, they might find themselves a lack of management knowledge or experience. Therefore, a lack of project manager can be quite common in this type of collaboration team. With regard to this limitation, we think a strategic communication plan for the collaborative team becomes more important, as it may compensate for the lack of a project manager by giving clear guidance on all the project communications.

6.2.3 Stage 3: Communication analysis

The strategic communication plan designed for academia-industry collaborative research project teams is intended to support a better management of the project, by achieving the goals which include but are not limited to:

- To foster more open and transparent communication;
- To ensure a consistent message;
- To ensure all the team members and stakeholders have an up-to-date information of the project progress;
- To facilitate team development;

6.2.4 Stage 4 & 5: Target groups, objectives and communication strategy

On one hand, in Chapter 4 we identified the key factors of academia-industry collaborative research projects success. Those key factors indicate what characteristics a project should have to be successful. On the other hand, for all the communications undertaken in a project team, the ultimate goal is to help the team achieve the success of the project. Therefore, those key factors are utilized to guide the setting of our communication objectives in the design of our communication plan. In Table 11 we present all the communication objectives which are 'translated' from those key factors and serve to help the project team to possess the characteristics a successful project should have.

Table 11 Communication objectives determined by the key factors of academia-industry collaborative research projects success

Common themes	Key factors	Communication objectives
Partners	Complementary expertise	- To get to know each member's expertise; - To evaluate the selection of research students;
Project management	Past collaboration partners	To build a strong and committed team;
	Clearly defined objectives	- To identify clearly defined and mutually agreed objectives for the project; - To inform all the team members and stakeholders of the project objectives;
	Clearly defined responsibilities	- To identify each member's responsibilities; - To inform all the team members of their own as well as other members' responsibilities;
	Mutually agreed project plan	- To work out a mutually agreed project plan; - To inform all the team members of the project plan;
	Realistic aims	To correct project direction if needed;
	Adequate resources	To allocate adequate resources needed for the project execution;
	Regular progress monitoring	- To inform about individual's working progress; - To inform about the team's working progress; - To inform about and visually show the periodic outcomes;
	Ensuring collaborators deliver	- To ensure collaborators deliver; - To present the final outcomes; - To discuss about the improvement;
Cultural gap	Cultural gap between academia and industry	- To raise issues that might affect project success; - To resolve issues before they impact the project ongoing;
Universal success factors	Mutual trust	To build a strong and committed team;
	Commitment	To develop trust amongst research students;

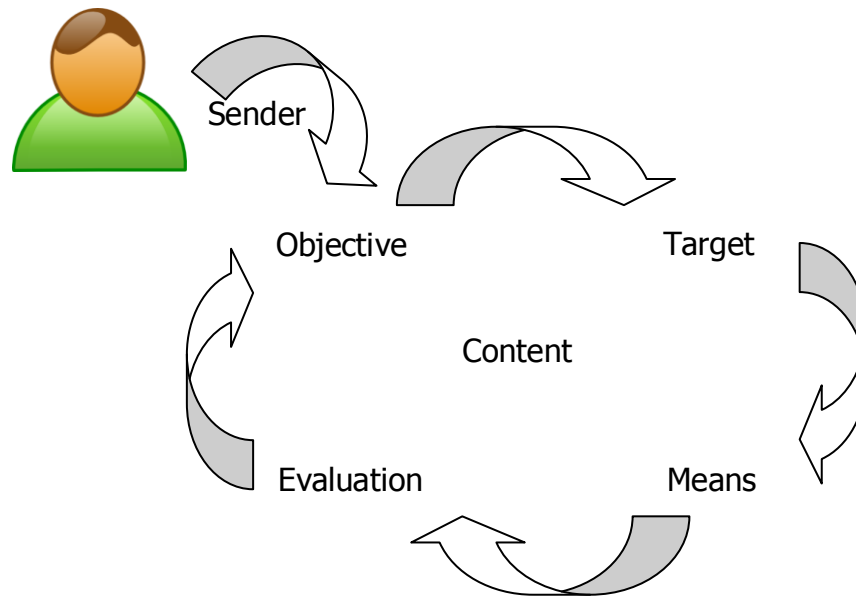


Figure 14 Knowledge transfer model

The 'knowledge transfer model' (Figure 14) illustrates the key components of a communication process, which include 'sender', 'objective', 'target', 'means', 'content' and 'evaluation'. Component 'evaluation' is not discussed in our communication planning since we think that component is more relevant when a communication plan is actually executed. We adopt all the other components for our communication plan and name them as 'communicators', 'communication objectives', 'audience', 'communication methods', 'communication content'. Keeping the 'communication objectives' we already set for our communication plan, below we analyze the other components.

With regard to the 'communication content', we think it is determined by the communication objective, as the content should serve to help achieve the objective. The content we identify for each objective is shown in Table 13.

For a typical academia-industry collaborative research project team, we can generally identify four involved parties: supervisors, research students, key stakeholders and others. The supervisor's responsibility is to give guidance to the research students with regard to the research planning, research conducting, etc. The research students are the real planners and executives. They need to follow every tiny aspect of the project. 'Key stakeholders', which refer to those who have interests in the collaborative research project such as the directors from the industrial company or the academic institute, tend to oversee the project progress and only expect milestone reporting. And 'others', which we refer to the people or parties that get connected to the project in certain ways, only needed to be communicated with when necessary. With regard to each party's role in the project and its communication needs, we choose different communication content to deliver to the party.

With regard to the 'communication methods', we identify some common methods used for project communications with their main advantages and disadvantages as listed in Table 12.

There is no such a thing as the best communication method. Depending on the communication objective, content and audience to reach, the most appropriate communication method can be varied. In our communication plan, we identify some methods that match each communication situation which is determined by the communication objective, content and audience (Table 13).

Last but not least, the 'communication frequency / timing' is also taken into account in our communication plan. It is mainly determined by the communication objective.

In the end, what we have achieved is a strategic communication mix based on the analysis of all the components of a communication process (Table 13).

Table 12 Main advantages and disadvantages of some common communication methods used for project communications

Communication methods	Advantages	Disadvantages
Steering group meetings	Offer the key members the opportunity to discuss important issues, such as project direction, status, policy;	Hard to organize as it needs all the key members to meet;
Informal meetings	Relatively easy to organize;	Not appropriate for critical issues to be discussed;
Project documentation	Keeps track of all the documents; Allows review anytime;	Only applicable for keeping track of the communication achievements;
Contract	A valid legal agreement to give guarantee;	The application of this method is limited;
Website or intranet board	Accessible to all team members; Information can be shared by all team members;	Costs effort to maintain;
Email	Fast and easy; It can carry text, audio and video files; No distance limit;	No group memory; Poor contextualization; Poor tool for managing documents;
Phone calls	Real time; Easy if team members are geographically distant;	No records of the conversation;

Table 13 Strategic communication plan for the academia-industry collaborative research project team

Communication objectives	Communication content	Communicators	Audience	Communication methods	Communication frequency / timing
- To identify clearly defined and mutually agreed objectives for the project; - To inform all the team members and stakeholders of the project objectives;	Project objectives	Supervisors and research students	Supervisors, research students and key stakeholders	- Steering group meeting - Project documentation - Posting on project website or intranet board	At the initial stage of the project
- To get to know each member's expertise; - To evaluate the selection of research students;	Expertise, knowledge and skills	Research students	Supervisors and research students	Meeting	At the initial stage of the project
- To identify each member's responsibilities; - To inform all the team members of their own as well as other members' responsibilities;	Responsibilities	Supervisors and research students	Supervisors and research students	- Steering group meeting - Project documentation - Posting on project website or intranet board	At the initial stage of the project
- To work out a mutually agreed project plan; - To inform all the team members of the project plan;	Project plan	Research students	Supervisors and research students	- Meeting - Project documentation - Posting on project website or intranet board	At the initial stage of the project
To ensure collaborators deliver	Collaborators' delivery	Supervisors, research students and stakeholders	Supervisors, research students and key stakeholders	- Steering group meeting - Contract	At the initial stage of the project
- To build a strong and committed team; - To develop trust amongst research students;	Project kick off	Research students	Research students	- Team-building exercises - Informal meetings	At the initial stage of the project
To allocate adequate resources needed for the project execution;	Resources	Research students	Interested parties	- E-mail - Phone calls - Meeting	At the initial stage of the project and ongoing as needed

Continued Table 13

Communication objectives	Communication content	Communicators	Audience	Communication methods	Communication frequency / timing
To inform about individual's working progress;	Individual status reporting	Research students	Research students	- Informal meeting - E-mail	Regularly scheduled
To inform about the team's working progress;	Team status reporting	Research students	Supervisors and research students	Team meeting	Regularly scheduled
- To inform about and visually show the periodic outcomes; - To correct project direction if needed;	Periodic outcomes	Research students	Supervisors and research students	- Presentation - Team meeting - Meeting minutes	Periodic, such as at the end of each phase
- To raise issues that might affect project success; - To resolve issues before they impact the project ongoing;	Issue reporting	Research students	Supervisors and research students	- E-mail - Phone calls	When issue occurs
- To present the final outcomes; - To discuss about the improvement;	Final outcomes	Research students	Supervisors, research students and stakeholders	- Presentation - Project formal report	At the end of the project

6.3 Conclusion

In this chapter we designed a strategic communication plan for the academia-industry collaborative research project team by utilizing the 'six-staged communication planning' method.

7 Conclusion, discussion and recommendations

7.1 Introduction

This research was divided into two parts. In Part I, we focused on the ACTA-DelltaTech collaborative research on the validation of the training effectiveness of the SIMENDO simulator. In Part II we focused on the evaluation of the ACTA-DelltaTech collaboration practice and the design of a communication plan for the academia-industry collaborative team. Conclusion, discussion and recommendations of Part I was already presented in Chapter 2. This concluding chapter is towards Part II of our research.

We start this chapter by answering the main research question (§7.2). After that we discuss the quality and limitations of the 2nd part of our research (§7.3) and give recommendations for future research (§7.4).

7.2 Conclusion

The main research question of this study is:

How can communication contribute to increase the probability of academia-industry collaborative research projects success – based on the case study of the ACTA-DelltaTech collaborative research project?

Here we give the answer to this question in three aspects:

Aspect 1: Academia-industry collaborative research projects success

To gain insights into the success (failure) of academia-industry collaborative research projects, we looked into the literature which was intended to identify the key factors of projects success. The comparative study showed that factors including 'complementary expertise', 'past collaboration partners', 'collaboration experience', 'understanding', 'communication frequency', 'clearly defined objectives', 'clearly defined responsibilities', 'mutually agreed project plan', 'realistic aims', 'adequate resources', 'regular progress monitoring', 'ensuring collaborators deliver', 'mutual trust', 'commitment' and 'continuity' were the most significant factors of academia-industry collaborative research projects success.

Aspect 2: The case of the ACTA-DelltaTech collaborative research project

The analysis of the way the ACTA-DelltaTech collaboration was undertaken decided that not all the key factors of academia-industry collaborative research projects success identified before were relevant for the evaluation of the ACTA-DelltaTech case. Factors used to evaluate the ACTA-DelltaTech case were 'complementary expertise', 'past collaboration partners', 'communication frequency', 'clearly defined objectives', 'clearly defined responsibilities',

'mutually agreed project plan', 'realistic aims', 'adequate resources', 'regular progress monitoring', 'ensuring collaborators deliver', 'mutual trust' and 'commitment'.

The main problems reflected in the evaluation of the ACTA-DelltaTech include:

- No past collaboration experience with each other;
- A lack of trust development;
- Email was the primary communication means;
- No joint project meetings;
- Lack of clearly defined responsibilities;
- Conflicts concerning equal contribution;
- Slow response from one supervisor;
- No contracts ensuring collaborators deliver;
- Different priorities of the collaboration.

Aspect 3: Effective management of academia-industry collaborative research projects

Without an effective management, no projects can success. To increase the probability of academia-industry collaborative research projects success means a more effective project management is required. In our study we approached this issue from the communication perspective. In the end, the solution we thought out for a more effective management of academia-industry collaborative research projects is a strategic communication plan. This plan includes all the key components of a communication process, which are 'communicator', 'communication objectives', 'audience', 'communication methods', 'communication content'. This plan is intended to compensate for the lack of a project manager in a typical academia-industry collaborative research project team by giving clear guidance on all the project communications.

7.3 Discussion

When studying sub-question 2, we did not intend to elaborate on or explore new factors of academia-industry collaboration success, but rather to focus on the success factors that were insistently identified in the published literature. Due to that reason, we employed a comparative study of selected literature to identify the key factors. One of the threats that could be imposed in this approach is that our control over the validity of those studies is limited. The extent to which those factors are associated with the collaboration success becomes difficult to determine and compare. One measure we took to compensate for this limitation is to set the threshold that only factor that was identified as the influential success factor in more than one study could be considered as a success factor with great significance.

Another limitation in this research is concerning the method we used for evidence collection of the ACTA-DelltaTech case. During the process of our evaluation of the ACTA-DelltaTech case, we were mostly at the mercy of subjective observation from one participant, since our request to interview the other three participants were declined.

Regarding the design of a communication plan for the academia-industry collaborative research project team, we intended to illustrate the staged planning method. It is a systematic way of setting up a communication plan. However, we can not deny that during the process

we simplified or idealized some situations. For example, the collaboration team which involves supervisors and students can have more than one structure. Due to the time limit of this research, we also intentionally leaved out the 'evaluation' stage of the communication planning, which is undoubtedly an important part of a complete communication plan.

7.4 Recommendations

With regard to the recommendations we gave for more effective management of academia-industry collaborative research projects, we did not evaluate their effectiveness or test their applicability in practice. We think future research could further test those recommendations through additional cases involving universities and industries engaged in similar collaborative research projects.

For future research, first further validation of those key factors of academia-industry collaborative research projects success is suggested. In our research, we used two angles to understand the context of those key factors in an academia-industry collaboration practice. One angle is the organizational level vs. the individual level. The other angle is the inter-relation vs. intra-relation. Considering the multiple stakeholders, types of partnership, collaboration purpose, etc., we think more angles could be explored to approach this subject. Of course all the theoretical findings would be best to test in the real cases.

With regard to the strategic communication plan designed for a more effective management of academia-industry collaborative research projects, we did not test its applicability in practice. We would like to see the application of this communication plan in a real project. Of course before that, an operational plan which fills the gap between the communication plan and its execution is required.

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Appendix

SIMULATION-BASED TRAINING AND ITS VALIDATION METHODOLOGY

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INTRODUCTION

SIMENDO dental training simulator is a simulation-based training (SBT) system lately developed by DeltaTech (Rotterdam, The Netherlands) for its client Academic Centre for Dentistry Amsterdam (ACTA). A research project which is aimed to validate the training effectiveness of this simulator on a clinical performance is established under the collaboration between DeltaTech and ACTA.

A comprehensive literature review is conducted before we examine the training effectiveness of SIMENDO simulator with the following objectives:

- To have a better knowledge of simulation-based training in medical education;
- To gain insights into the current state of validation methodologies in medical SBT;
- To develop an appropriate research design for the SIMENDO simulator validation study.

In the following sections we start out with the definition of SBT, followed by the rationale of SBT in medical education and its classification. Next we look into the validity studies and the current state of validation methodologies in medical SBT. Then we present the randomized-controlled trial (RCT) design and argue why RCT is the appropriate experimental design for our study. A systematic literature review is also conducted to construct a framework for RCT design. Finally, a well-developed research design with the core of an RCT design to examine the training effectiveness of SIMENDO simulator is presented.

SIMULATION-BASED TRAINING

What is simulation-based training?

Simulation, as defined by anesthesiologist and simulation pioneer Gaba (2004), "is a technique to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner." Simulation-based training (SBT), which relies on simulation technology, is a new way for trainers and instructors to prepare their students in a simulated environment which is representative of actual operational conditions, enabling them to better and more rapidly match a real-life situation to their training experiences and respond as trained. SBT first appeared in the training of civilian and military personnel (Reznek et al, 2002). Later the application of SBT has increasingly widespread into a variety of professions and disciplines. The first case of SBT in medical community was the patient anesthesia simulator introduced in 1969 by Denson and Abrahamson to augment resident training. Since then, increasingly sophisticated developments have occurred worldwide to improve the learning of individual and team reasoning, communication, and technical and other skills through the development of medical skills laboratories that employ various levels of simulation (Maran et al, 2003 & Gorman et al, 2000).

Why do we need simulation-based training in medical education?

The current medical education framework is based on the premise that trainees will obtain the necessary expertise by observing and working closely with expert practitioners (Patel et al, 2006, Dutta et al, 2006 & Riles, 2005). Desser (2007) pointed out that this "master-apprentice" model had its limitations such as:

1. Trainees' different intrinsic aptitudes and different rates of skills acquisition are not addressed in the current training method;
2. Attending physicians' evaluations of trainees' performance is subjective and they invariably exhibit the common biases prevalent in performance assessment;
3. Trainees don't participate actively in the learning process and are not provided with timely and appropriate feedback;
4. Trainees' exposure to a wide variety of cases diminishes as duty hours are limited and procedures migrate to the outpatient setting.

Dunkin et al. (2007) indicated that the limitations of current training method could be improved by simulation-based training as SBT offers the opportunity for the rehearsal of a wide range of skills in a controlled, risk-free environment, allows for the development of mastery at a pace appropriate to the learner and provides hands-on experience and immediate feedback, and a means for objective, standardized verification of skills.

Types of simulators

Simulation-based training always involves a simulator which is a system that replicates the real life environment. In a review of the simulators in surgical training, Hammoud (2008) identified two types of simulators with regard to their level of fidelity: low-fidelity and high-fidelity. The fidelity of a simulator is determined by the extent to which it provides realism through characteristics such as visual cues, tactile features, feedback capabilities and interaction with the trainee (Hammoud, 2008).

High-fidelity simulators provide the trainee with additional real-life cues to immerse them in a more realistic interactive scenario and environment. Simulators in this category include virtual reality simulators, procedural simulators and animal models.

Low-fidelity simulators typically serve to practice isolated procedures such as knot tying. Simulators in this category include bench models and video box trainers.

In his study, Hammoud also summarized the measurement method, advantages and disadvantages of each type of simulator.

VALIDATION OF MEDICAL SIMULATION

With current software, it is possible to design any number of virtual environments to simulate a variety of tasks. The difference between a useful simulation and a mere computer game based on a medical scenario is the degree to which the exercise meets the validity criteria (Desser, 2007).

Types of validity

It is notable that the definition of validity is not consistent throughout the surgical literature (Aucar et al, 2005 & Van Nortwick et al, 2009). Most discussions about validity stem from the social and behavioral sciences. There are four types of validity associated with the effectiveness of a SBT intervention: 1) face validity, 2) content validity, 3) concurrent validity and 4) predictive validity.

FACE VALIDITY describes whether the system looks like what it is designed to represent, in other words, if it is sufficiently realistic for the user to suspend disbelief while performing the simulated task (Desser, 2007).

CONTENT VALIDITY describes the extent to which a simulation exercise reproduces all aspects of the real-world experience (Desser, 2007).

CONCURRENT VALIDITY describes how closely subjects' performance on a simulator correlates with their performance on a gold standard measure of proficiency (Desser, 2007).

PREDICTIVE VALIDITY describes the extent to which good performance on the simulator predicts good performance on real patients (Desser, 2007).

Current state of validation methodology in medical SBT

Although the importance of simulation as an educational tool for teaching surgical technical skills is increasingly recognized in the medical community, literature examining the efficacy of simulation-based training remains inconsistent and limited (Aucar et al, 2005 & Van Nortwick et al, 2009). One reason for this variability and limitation is the lack of rigor involving psychometric measurements reported in studies of SBT interventions (Van Nortwick et al, 2009). A comprehensive qualitative review by Feldman et al (2004) concluded that "significant design flaws" in the reviewed studies caused a "lack of standardization in tasks, metrics, and level of validation". Deficiencies and heterogeneity in validation study methodologies have been cited repeatedly as major limitations to drawing strong conclusions comparing the effectiveness of SBT and evaluating the transfer of skills from the simulation setting to the operation room (Sturm et al, 2008). The recent Cochrane review of randomized-controlled trials investigating the effectiveness of SBT concluded, "Research of higher methodological quality is needed" (Gurusamy et al, 2009). Therefore, before examining the effectiveness of SIMENDO simulator, we think a review of simulation-based training with attention to validation methodology is quite necessary.

RANDOMIZED-CONTROLLED TRIAL

According to the Cochrane Glossary⁹, a randomized-controlled trial (RCT) is “an experiment in which investigators randomly allocate eligible people into intervention groups to receive one or more interventions to be compared”. Such type of scientific experiment is most commonly used in testing the efficacy or effectiveness of healthcare services (such as medicine or nursing) or health technologies (such as pharmaceuticals, medical devices or surgery). RCTs are also employed in other research areas, such as judicial, educational and social research. The first instance of using a rigorously designed RCT study was an experiment conducted by the British Medical Research Council (1948) which occurred in the 1940s. It involved 107 soldiers with acute progressive tuberculosis (TB) who were treated by the then experimental drug streptomycin.

RCTs are superior for comparing interventions, which include simulation-based training interventions, for the following reasons as summarized by Green (2000):

- Bias, whether conscious or unconscious, is avoided;
- Predictive factors, both known and unknown, tend to be balanced between intervention and control groups;
- Use a concurrent control group controls for trends in time;
- Randomization provides a valid means for evaluating the probability that two groups of patients receiving equivalent drugs or treatments will have different outcomes because of chance alone;
- Results from well-designed clinical trials are more likely to be convincing.

Till June, 2006, only two systematic reviews of the effectiveness of medical simulators were identified (Lynagh, 2007). Both reviews indicated that the RCT design was the experimental design most applied in studies of effectiveness validation. Thus, we identify the randomized-controlled trial as the appropriate experimental design for the SIMENDO simulator validation study. However, some disadvantages of RCT pointed out by Levin (2007) should be taken into account before we apply RCT design for our study:

- High dropout when the intervention has undesirable side-effects or there is little incentive to stay in the control group;
- Ethical considerations may mean that a research question cannot be investigated using the RCT design;
- For a descriptive overview it may be cheaper and easier to use an observational design;
- Prior knowledge is required about the level of improvement that is clinically meaningful and the expected variation of improvement in the sample in order to calculate the sample size. These facts are often not known.

TOWARDS A FRAMEWORK FOR AN RCT DESIGN

The framework construct starts with a systematic literature search. Studies that qualify the predefined criteria are first identified. Then a review of the identified studies is conducted to

⁹ <http://www2.cochrane.org/resources/glossary.htm>

construct the framework with a “from disassembling to re-assembling” approach. Within this approach, identified RCTs are first broken apart, delineating the essential components of an RCT design, followed with an analysis of each component and finalized with a re-assembling procedure to put all components together for a complete framework.

Literature search

PHASE 1: SEARCHING

This phase is intended to search for papers that are broadly concerned with validation of simulator training effectiveness involving an RCT design in the Science Direct and Web of Knowledge databases. The search is limited to the time period after the year 1998 as previous reviews indicate that the majority of published research in this field appeared after that year (Sutherland et al, 2003 & Issenberg et al, 2005). Keywords used for search include “simulator training”, “virtual reality training”, “randomized-controlled trial”, “training effectiveness” and “transfer validity”. They are placed into categories and assigned keyword numbers to allow strategic combination to form search strings.

Table 14 Keywords derived from the research topic are assigned into 3 categories

Keyword 1	Keyword 2	Keyword 3
simulator training	randomized-controlled trial	training effectiveness
virtual reality training		transfer validity

PHASE 2: SCREENING

The result of each search string is assessed on screen with predefined criteria as follows:

- i. The paper is written in English;
- ii. The full-text of the paper is accessible;
- iii. The study is evidence-based;
- iv. The study is well-validated;
- v. The study must evaluate a training simulator for the purpose of medical education or procedural skill training;
- vi. The study must utilize a randomized-controlled trial design in evaluating the intervention;

The removal of duplicate references reduces the number of potential studies. And a further examination by abstract and full-text is also conducted to refine the results.

Table 15 Searching and screening results for each search string. The numbers indicate the numbers of references left in the pool.

nr.	Search string	searching results		screening results	
		SD ¹⁰	WOK ¹¹	SD	WOK
1	simulator training AND randomized-controlled trial AND training effectiveness	1	7	0	0
2	simulator training AND randomized-controlled trial AND transfer validity	1	2	1	1
3	virtual reality training AND randomized-controlled trial AND training effectiveness	0	11	0	0
4	virtual reality training AND randomized-controlled trial AND transfer validity	1	2	0	0
5	simulator training AND randomized-controlled trial	16	56	0	1
6	virtual reality training AND randomized-controlled trial	8	48	0	0

PHASE 3: SELECTING

Finally, three qualified studies, as listed below, are identified for further review.

Case 1	•Park (2007), "Randomized Controlled Trial of Virtual Reality Simulator Training: Transfer to Live Patients"
Case 2	•Verdaasdonk (2007), "Transfer Validity of Laparoscopic Knot-tying Training on a VR Simulator to a Realistic Environment: a Randomized Controlled Trial"
Case 3	•Lucas (2008), "Training on a virtual reality Laparoscopic Simulator Improves Performance of an Unfamiliar Live Laparoscopic Procedure"

Framework for an RCT design

Disassembling the three RCTs illustrates the essential components of an RCT design, which are graphically presented in Figure 1. An analysis of each component is followed.

¹⁰ SD: Science Direct database.

¹¹ WOK: Web of Knowledge database.

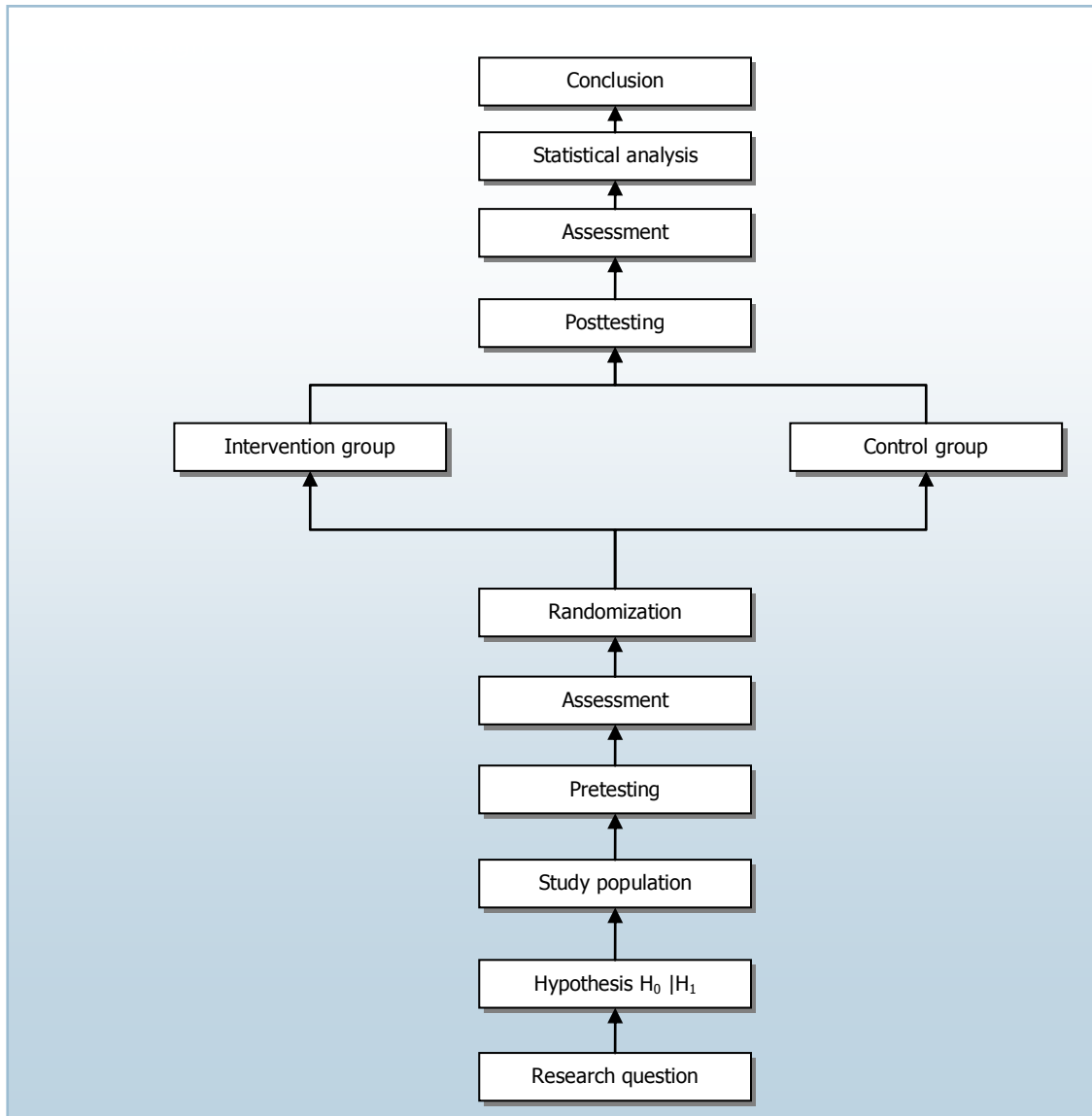


Figure 15 Framework for an RCT design

Any research, regardless of design, starts with a clearly defined **RESEARCH QUESTION**. The research question further leads to a **NULL HYPOTHESIS** and at least one **ALTERNATIVE HYPOTHESIS** which the researcher aims to test against in the study. In an RCT design, the null hypothesis is usually accounted for the control group whereas the alternative for the intervention group. Reviewing the three RCT studies, it is not difficult to recognize the hypotheses those researchers might have formulated for their studies though they were not laid out in paper.

Table 16 Research question, null hypothesis and alternative hypothesis of each RCT study

RCT 1	
Research question	Whether training on a computer-based colonoscopy simulator outside the endoscopy suite improves performance on a resident's first patient colonoscopy in a clinical setting?
Null hypothesis	Residents who get trained on a computer-based colonoscopy simulator prior to their first patient encounter do not perform better in the clinical setting than those who do not get trained.
Alternative hypothesis	Residents who get trained on a computer-based colonoscopy simulator prior to their first patient encounter perform better in the clinical setting than those who do not get trained.
RCT 2	
Research question	Whether knot-tying training on a VR simulator leads to the transfer of skills to a realistic environment (anaesthetized porcine model)?
Null hypothesis	Participants who receive knot-tying training on a VR simulator can not tie a double laparoscopic knot in a realistic environment faster and do not make fewer errors than those who do not receive training.
Alternative hypothesis	Participants who receive knot-tying training on a VR simulator can tie a double laparoscopic knot in a realistic environment faster and make fewer errors than those who do not receive training.
RCT 3	
Research question	Whether training on a VR laparoscopic cholecystectomy simulator improves the performance of a live, unrelated laparoscopic urological procedure?
Null hypothesis	The scores of students who get trained on a VR laparoscopic cholecystectomy simulator will not be significantly different or significantly lower than those of students who do not get trained.
Alternative hypothesis	The scores of students who get trained on a VR laparoscopic cholecystectomy simulator will be significantly higher than those of students who do not get trained.

Besides hypothesis generation, the research question also informs the STUDY POPULATION. An RCT requires the use of a carefully defined and assembled population and identifies the population according to predefined INCLUSION AND EXCLUSION CRITERIA. In the three studies, we notice that the selection of subjects' discipline and study year may differ due to different surgical procedures of interest, but the exclusion criteria "no prior relevant experience is expected" are identical.

Once the Inclusion and Exclusion criteria are implemented, a certain population can be identified. Then we need to figure out how many subjects we should include, namely the SAMPLE SIZE. Previous studies in skill training and transfer indicate that to detect an effect with sufficient reliability, a minimum of 13 subjects in each group is recommended. During the study design, this minimum size should be kept in mind. However, we should also know that in reality not every research can meet such requirement. For example, both RCT 1 and RCT 2 fail to reach that sample size.

The main part of an RCT design employed to investigate the effectiveness of a training simulator is composed of three stages: 1) pretesting, 2) simulator training and 3) posttesting.

STAGE 1: PRETESTING

In stage 1, a pretesting may be conducted for one or more of the following purposes:

- To ensure a standard level of background knowledge with respect to the procedure and instrument handling;
- To provide statistical evidence that there are no significant differences between two groups before simulator training;

More concrete measures can be taken to realize those purposes. For example, in RCT 1 and RCT 3, a video introduction or demonstration of the studied surgical procedure for the subjects is prepared by the researchers to guarantee a standard level of knowledge. Researchers can also authorize the subjects with sufficient trials of the instrument. If researchers tend to prove that the comparative groups have no difference before training, a quantitative assessment should go along with the pretesting for statistical analysis. In the three RCTs, subjects are pretested with the procedure of interest on the simulators. However, we think the option of pretesting subjects in the clinical setting or on the real instrument is also acceptable.

A validated ASSESSMENT METHOD should be identified for both pretesting and posttesting. The assessment can be subjective, objective or the combination of both. In the three RCTs, we can see that researchers tend to use the objective, quantitative assessment as it provides high level of objectivity, high coherence and convenience for analysis. It is true that in those RCTs researchers also use experts to evaluate the performance. But we should notice that a well-validated global rating scale is introduced in expert assessment. Such standardized scale will minimize the subjectivity. In case there is no well-validated global rating scale established for the procedure of interest, we think researchers should better stay with the objective assessment. Another issue that comes into concern when the assessment involves more than one method is the concurrent validity. Correlations among several assessment results of the same performance should be tested.

Following the pretesting, there lies an important procedure before we move to stage 2 and that is RANDOMIZATION. In an RCT design, randomization refers to random allocation of population members into two groups. But this procedure is not specifically explained in those three RCTs. Only using closed envelopes is mentioned as a method to realize randomization in RCT 2. Meanwhile, we also notice in those three RCTs that after the randomization, two groups for comparison have the equal size. This is probably due to researchers' concern of imbalance. As most statistical tests are most powerful when the groups being compared have the equal size and it is especially important when the sample size is small ($n < 200$).

STAGE 2: SIMULATOR TRAINING

The two established groups bring the progress to the stage of simulator training. In terms of an RCT, the simulator training we study here is an INTERVENTION. The group to which researchers introduce the simulator training is called the INTERVENTION GROUP. The CONTROL GROUP is the one which simply lacks an intervention. The three RCTs share the same intervention as simulator training whereas the content, amount, time distribution differs from study to study. Sometimes the amount of an intervention variable will have a different effect on outcomes (the so-called 'dose effect'). According to the research aim, researchers can design the training program with respect to its content, amount, time distribution, etc. In terms of the control group, many might equate its status with receiving a placebo, namely to be 'ignored' by researchers. Actually the control group does not necessarily have to receive

nothing. For example, in RCT 2 subjects in the control group view three consecutive video demonstration of the VR knot-tying procedure on the simulator as it is hypothesized that additional manual training on the simulator would be more effective than repeated video viewing of the same procedure on the VR simulator. This point is more obvious in clinical medicine as the control group patients typically receive the standard or conventional care, mostly for ethical reasons.

To guarantee the STANDARDIZATION of the training session, a detailed training protocol should be established in advance. It should include the information about:

- 1) The training program;
- 2) What should be done if the subject makes critical flaws;
- 3) In which condition researchers can give instructions to the subject;
- 4) Restriction upon the control group's accessibility to the training session;
- 5) Other rules and conditions researchers think necessary to state.

STAGE 3: POSTTESTING

In this stage, all subjects are asked to perform the defined procedure in a clinical setting or on a real instrument. As stated before, an appropriate assessment method should be identified for it. Depend on the type of measurement involved in the assessment, an appropriate STATISTICAL ANALYSIS METHOD should also be identified. In RCT 1, researchers apply chi-square tests for outcomes on nominal scales and independent groups t test for measures on interval scales. Whereas, in the other two RCTs, Mann-Whitney U test is chose for the non-parametric data. Of course, other analysis methods such as ANOVA may also be appropriate. No matter which analysis method researchers choose, they are attempting to answer the same question, whether introducing the intervention variable into the intervention group will produce an outcome different from the absence of that variable. And with the statistical analysis result, now researchers can reach the final CONCLUSION.

Table 17 A comprehensive comparison of three RCT studies

	Case 1	Case 2	Case 3
study population	residents in postgraduate 1 st to 3 rd year in the general surgery and internal medicine programs	1 st and 2 nd year surgical trainees	1 st and 2 nd year medical students
Inclusion & Exclusion criteria	Subjects with prior experience in endoscopy are excluded.	Subjects with prior experience in laparoscopic knot-tying or suturing are excluded.	Subjects with prior experience in laparoscopy are excluded.
sample size	n=24	n=20	n=32
apparatus	AccuTouch colonoscopy simulator	SIMENDO simulator	Lap Mentor
pretesting	1) All subjects watch a video introduction to colonoscopy; 2) All subjects are given opportunity to familiarize themselves with the components and handling of a colonoscope; 3) All subjects are immediately pretested on the colonoscopy simulator using module 1, with a time limit of 30 minutes.	1) All subjects undergo eye-hand coordination training with basic drills on SIMENDO simulator.	1) All subjects are given a demonstration of a simulated cholecystectomy; 2) All subjects perform a VR laparoscopic cholecystectomy on the simulator.
simulator training	• Intervention group: subjects practice independently for 2-3 hours; • Control group: subjects receive no training.	• Intervention group: subjects practice VR training knot-tying module for at least 10 times double knot; • Control group: subjects view three consecutive times video demonstration of the VR knot-tying procedure.	• Intervention group: subjects practice 6 training sessions of 30 minutes each, 8 simulated tasks; • Control group: subjects receive no training.
posttesting	All subjects perform a patient colonoscopy with a maximum of 30 minutes.	All subjects perform a suturing task on a porcine model.	All subjects perform a porcine laparoscopic nephrectomy.
assessment	• pretesting: computer-generated parameters & expert global rating scale; • posttesting: ability to reach the cecum & absence of critical flaws & expert global rating scale.	• pretesting: no • posttesting: expert global rating scale & task time & predefined errors.	• pretesting: expert global rating scale; • posttesting: expert global rating scale.
statistical analysis	Chi-square & T-test	Mann-Whitney U test	Mann-Whitney U test

RANDOMIZED-CONTROLLED TRIAL DESIGN FOR VALIDATING THE TRAINING EFFECTIVENESS OF SIMENDO DENTAL TRAINING SIMULATOR

The well-constructed framework in previous section provides a good guidance for further development of an RCT design for the SIMENDO simulator validation study. Given the research conditions of our study, some adjustments need to be made based on the RCT framework.

The goal of SIMENDO simulator study is to validate its training effectiveness. Such a goal indicates the following research question:

Whether training on SIMENDO dental training simulator improves dental trainee's performance with a real dental scanner?

Here, the improvement of performance refers to the shortening of the time required for tooth scanning. In our study one-quadrant scanning is intended to indicate the general tooth scanning. This clarification also helps to formulate the following hypotheses for the research:

H_0 (null hypothesis): As a result of the training on SIMENDO dental training simulator, there will be either no significant difference in task time for one-quadrant scanning or a significant increase.

H_1 (alternative hypothesis): As a result of the training on SIMENDO dental training simulator, there will be a significant decrease in task time for one-quadrant scanning.

The research question also indicates the study population which is the dental trainee. A set of Inclusion and Exclusion criteria is further defined with reference to those employed in similar studies. Prior to its implementation, this research project is approved and supported by both DeltaTech and ACTA. 12 dental trainees of the 5th year at ACTA who enroll for course Crest volunteer to participate in this research. They all meet the Inclusion and Exclusion criteria. Although a minimal size of 26 subjects is recommended for a good effect as stated before, we do not manage to include more than 12 subjects within the institution.

Two apparatuses are used in this research. The clinical tooth scanning will take place on the 3M LavaTM Chairside Oral Scanner C.O.S.. And the training session will take place on SIMENDO dental training simulator.



Figure 16 Two apparatuses to be used in the research with 3M Lava™ Chairside Oral Scanner C.O.S. (top) and SIMENDO Dental Training Simulator (bottom)

STAGE 1: PRETESTING

In this stage, the pretesting is intended to be conducted for two purposes:

- To ensure a standard level of background knowledge with respect to the tooth scanning procedure and the handling of SIMENDO dental training simulator and dental scanner;
- To provide a reference of comparison within the group.

A video instruction of tooth scanning procedure will be prepared for the subjects. They are also informed of the criteria for a qualified tooth scanning with examples. In terms of the instrument handling, a demonstration with both the simulator and dental scanner will be given. Moreover, the subjects will be given enough time to familiarize themselves with the components and handling. After that all the subjects will be immediately pretested on 3M Lava scanner with the task of scanning Quadrant 3 and Quadrant 4.

In terms of the procedure of tooth scanning, so far there is no well-validated global rating scale established according to our knowledge. That's why we decide to choose objective

assessment over subjective one. Time taken to finish a qualified one-quadrant scanning is measured to assess the performance. There is no system which indicates the completion of a qualified one-quadrant scanning available within 3M Lava scanner. It means the completion of the tooth scanning has to be decided by the researchers. Two measures will be taken to guarantee the standardization of assessment among all the subjects. One measure is that researchers reach an agreement on the criteria for a qualified one-quadrant scanning prior to the test. The other measure is that all the tooth scanning results are video-recorded for afterward peer double evaluation.

To sort the subjects into two groups for the following stage of simulator training, a randomized procedure, random number assignment, is designed for this research. Each subject is randomly assigned a number and that number decides which group that subject will belong to. First, 12 cards with numbers 1-12 are prepared. Each subject draws a card with a certain number. If the number the subject gets is odd, then that subject is assigned to the intervention group. Otherwise with an even number, that subject is assigned to the control group. As the numbers 1-12 are evenly distributed between odds and evens, the equal size of two groups with 6 subjects each is also guaranteed.

STAGE 2: SIMULATOR TRAINING

In this research, the intervention that the research question refers to is simulator training. This concept should be further operationalized. SIMENDO dental training simulator consists of several tasks for eye-hand coordination skills training as mentioned in Figure 2. Feedback from the dentists who participated in the trial of the simulator training earlier says that the plane scanning and the side scanning are the most essential tasks to master tooth scanning. Therefore these two tasks are selected to be incorporated in the training session. Subjects are allowed to practice each task with a maximum of 5 times. The task time is measured within the simulator system to indicate whether the subject has passed the predefined baseline. Once the subject passes both tests twice, which is to avoid chance of luck, but not necessarily consecutive, the training session stops immediately. If the subject has used up 5 times while is still unable to pass the test, the training session also stops. A clear definition of the training session along with the conditions should be stated in the training protocol.

This training session is assigned to the intervention group. Subjects from the control group receive no training and are not allowed to attend or view the training session. This rule should also be included in the training protocol.

Here is the complete training protocol established for this research:

- 1) the training session
 - i. takes place on SIMENDO dental training simulator;
 - ii. one training session is composed of two tasks: plane scanning and side scanning;
 - iii. subjects are expected to pass the tests twice, but not necessarily consecutive;
 - iv. once the subject has passed the tests twice, the training session stops immediately;
 - v. if the subject has used up 5 times for one task while is still unable to pass the test, the training session also stops.

- 2) If the subject cannot finish one practice within 5 times of the minimal time required, the researcher is allowed to take over the task and help the subject finish it.
- 3) During one practice, researchers are not allowed to give any instruction to the subject. But between two practices, researchers can give instructions if necessary.
- 4) When subjects from the intervention group are receiving the training session, subjects from the control group are not allowed to attend or view the session. They are also not allowed to have any communication with the subjects from the other group during that period.

STAGE 3: POSTTESTING

The content of posttesting is the same as pretesting. All subjects are asked to perform the task of scanning Quadrant 3 and Quadrant 4 on 3M Lava scanner. Also as pretesting, time required to finish a qualified one-quadrant scanning is measured.

Until then researchers will have collected all the data for further analysis. There are two factors which may have effects on the variable of task time of one-quadrant scanning. A one-quadrant scanning can be done in pretesting or posttesting and by a subject who receives simulator training or not, which implies that there are two factors that may have effects on the task time. One factor is trial, which refers to whether the scanning takes place in pretesting or posttesting. The other factor is group, which refers to whether the scanning is performed by a subject receiving the simulator training or not. We are not only interested in the effects of those two factors but also the interaction between the two factors with respect to their effect on the task time of one-quadrant scanning. Therefore, two-way ANOVA test is used to examine the effects and test against the hypothesis. Finally, based on the statistical analysis result, conclusions can be drawn.

The complete research design with the core of an RCT design for validating the training effectiveness of SIMENDO dental training simulator is presented in Figure 3.

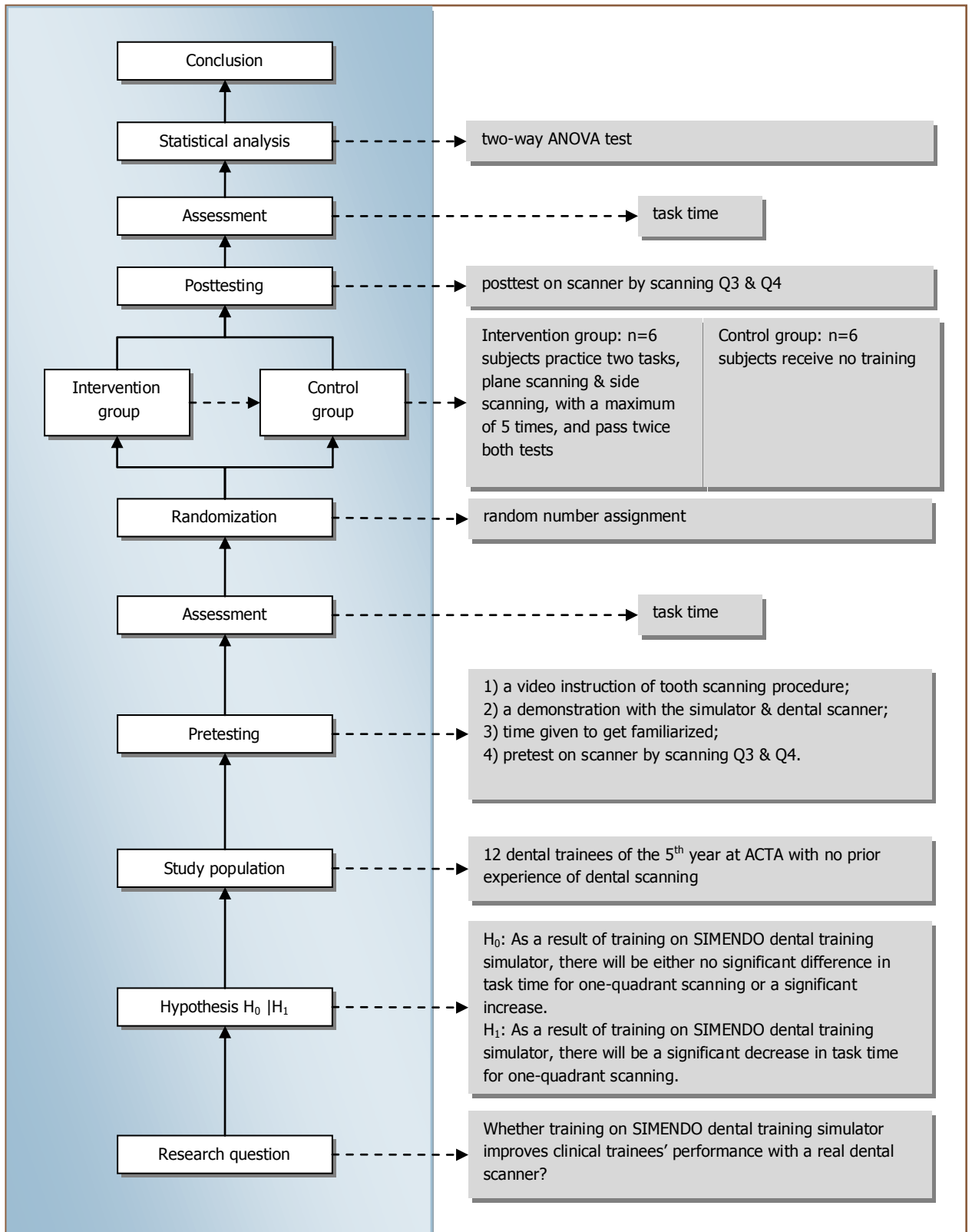


Figure 17 RCT design for the research "Validation of the training effectiveness of SIMENDO dental training simulator", which is developed based on the framework for an RCT and takes the research conditions into account.

CONCLUSION

This literature review summarized some key concepts of the subject "simulation-based training" in medical education. The current body of SBT literature shows there is a lack of standardized validation methodologies. Hence we tried to strengthen the rigor of our validation study by building a standardized framework. We investigated into validation methodology and identified the randomized-controlled trial as the appropriate design. With a comprehensive review of three well-selected RCT studies, we constructed a framework for an RCT design with a "from disassembling to re-assembling" approach. Such a framework further guided the development of a research design for the study "validation of the training effectiveness of SIMENDO dental training simulator". The adoption of the RCT framework developed in this review for simulator effectiveness study may not only enhance the research's methodological strength but also improve comparisons across studies.

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