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RESEARCH EDUCATION NURTURES INQUISITIVENESS OF PROFESSIONAL DESIGN AND ENGINEERING STUDENTS

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ABSTRACT
In this paper we report on the evaluation of our research education across a range of professional design and engineering majors. Through inspection of educational materials, interviews with teams and a questionnaire among our students we examined to what extent our approach to teaching research was effective for increasing inquisitiveness. Of particular interest were the effectiveness of the triangulation first pedagogy and the uses of the DOT-Framework in our university of applied sciences, which we described in earlier papers in this conference series. We found that (1) the triangulation first approach and (2) attention for research in general throughout the curriculum, increases students' inquisitiveness. To this end: teacher-led education and master-apprentice turned out to be good didactic approaches, whereas unsupervised learning of research skills turned out to be ineffective. Our findings suggest that teaching research can be a valuable part of design and engineering education, but only if it is carried out with care.

Keywords: Research education, DOT-Framework, Inquisitiveness, Inquiry-based attitude, triangulation first pedagogy

1 INTRODUCTION

Research education has not always been a natural part of higher professional engineering and design programmes in the Netherlands. In recent years this changed as an effect of the European agreements of Lisbon and Bologna [3]. Since then, efforts have been made to give research topics: design research methods, the research cycle, and academic standards such as validity and reliability, for example, a place in the curricula. A particular challenge for all universities of applied sciences was to integrate these new topics into curricula, in such a way that research is taught as a means to improve professional practice and not as an end in itself [2,3].

In this paper we report on an evaluation study comparing eight different implementations of a proposal for integrating research in professional design and engineering programmes. Through inspection of learning materials, interviews with teachers and a student questionnaire, we tried to get an overview over the adopted teaching practices for research in our institute and their respective effectiveness. We used inquisitiveness as our primary outcome measure. We were particularly interested in the effectiveness of research education using the Development Oriented Triangulation (DOT)-Framework and – correspondingly - the effectiveness of the 'Triangulation First' pedagogy utilizing this framework [14, 15]. In the rest of this paper we will first provide a sketch of the curricula followed by a general outline of our approach and a discussion of our most noticeable results.

2 CONTEXT: A SKETCH OF OUR PROGRAMMES

Our academy is training about 2500 students across design and engineering majors such as interaction design, media management, Business IT and management and software development.

After following propaedeutic programmes of one year, a student chooses a major belonging to either the communication design programme or the information technology programme. Each major, in turn, consists of three large educational blocks of one semester featuring two courses (7, 5 EC) and a project

(15 EC) which are thematically related. Apart from these three semesters students follow an internship (30 EC), a minor (30 EC), and a graduation internship project (30 EC).
Within some general constraints, the core staff of each major has had the freedom to carry out research education in a way that is most fitting to the context of the major. This means different majors have chosen a different subset of research topics to teach and employ different didactics. A shared constraint for all majors was the *amount* of research education in the programme: 2, 5 EC in the first and second semester of the major and 7, 5 EC in the final semester.
The teams of all majors were advised to use the DOT-framework [14, 15] as a shared language for research and a common methodological backdrop and most teams used it one way or the other. The DOT-framework offers a systematic account of the ontological, epistemological and axiological nature of five distinct research strategies. Research methods can be categorised within these strategies. The *Library* strategy focuses on gaining an overview of existing work such as a literature search or a competitor analysis. *Field* research helps to get an overview of the application context, for example through surveys or ethnography. With *Lab* research one can test a design proposition in the application context, such as through a usability test or an A/B test. *Showroom* research helps to compare the design proposition with existing work, such as in a heuristic evaluation or peer-review. *Workshop* methods aim at (iteratively) exploring the innovation space, for example through ideation or morphological techniques.For more details we refer to the original publications [14,15] and to the card set with specific design research methods for communication design [4] and the information technology majors [5]. The general idea is that any path from a problem to a solution requires several of these strategies in a mixed-methods research design.
Note that in our academy research is always taught as an integrated part of existing courses, and not, generally, as a separate course. So research education is the responsibility of the general teaching staff and not of separate teachers, specifically hired to teach research topics. The advantage of this integrated approach is that there is a natural pressure to highlight the relevance of research to the profession, but the drawback is that a part of the staff is uncomfortable with research as a subject matter in their courses.

3 SETUP OF THE EVALUATION

3.1 General setup

As the core staff of each major had created their own research education programme it required a thorough examination of all available material to get to an overview that could serve as a basis for comparison of these different programmes. Figure 2 depicts the overall approach of our evaluation.

Figure 1. General setup of the evaluation study

First, we went through the teaching materials of each major to get a first impression of the programme and the approaches used for teaching research. Second, we held interviews with the core staff of each major. These first two steps lead to a fairly diffuse picture of the different programmes. The materials for teaching research topics were in many cases scattered across the whole programme and often not explicitly labelled as such. The interviews also revealed that teachers had very different notions of research education. As such we produced uniform outline sheets for each major telling which elements of research were covered where, the didactic approaches used and how research was part of the examination of the major. These sheets were sent back for feedback to the teaching teams (member-check) and adjusted based on the feedback. Next, we prepared a student questionnaire.

3.2 Student Questionnaire

The student questionnaire included four outcome variables: inquisitiveness, self-efficacy for research, self-efficacy for the DOT-Framework and knowledge of the DOT-Framework. Our teaching staff considers *inquisitiveness* as the most important goal of research education; it is the sole focus of this paper.

Researchers have particular dispositions in the way they examine the world and solve problems. Several technical terms have been proposed to denote these dispositions such as: research (ers) attitude [6], scientific research disposition [12], inquiry based attitude [7] and inquisitiveness [1]. We prefer the term inquisitiveness as we see it as a natural human trait, that can be nurtured in and developed through education [14], but we use the operationalization of van der Rijst [12], who prefers the term scientific research disposition. In this operationalization inquisitiveness is characterized by (1) an inclination to criticize, (2) an inclination to understand, (3) an inclination to achieve, (4) an inclination to share, (5) an inclination to innovate, and (6) a desire to know. To measure inquisitiveness we use a shortened version of a validated questionnaire [8], containing 15 questions. Although the questionnaire was based on the elements of inquisitiveness which van Rijst [12] provided, it did not discern between these separate elements. Rather, it treated inquisitiveness a single factor underlying all questions.
The questionnaire was administered in April and May 2017 which is the last project period of the year. The total population consisted of 1128 students, in the first, second and third year of which 353 responded. The response rate was satisfactory: we managed to get an average response rate over 40%, with a minimum response rate of 20% per educational unit. In September 2017 we administered the questionnaires to freshmen in their first year in their study week to enable a comparison with students at the end of the first year. We administered the questionnaire only once in different cohorts, so comparisons between 1st, 2nd and 3rd years could possibly be explained by changes in the curriculum over the years rather than by growth through the years as a result of a stable programme.
Our choice for a self-reporting questionnaire for inquisitiveness made it possible to compare groups within our institute, but the results cannot be interpreted as external indicator of inquisitiveness such as made by teachers or external experts using international standards. We could not find a manageable way to incorporate such an expert assessment into our evaluation.

3.3 Effectiveness analysis

As we were interested in the effectiveness of the different approaches to teaching research in our university we tried to relate the different educational approaches that we found in the first phase of the study to the outcome measures of the student questionnaire. For this we created a coding scheme quantifying the outline sheets that we'd created. This allowed a quantitative investigation of the effects of different didactics on inquisitiveness. More details about the setup and reliability of this coding are provided in section 4.4.

4 FINDINGS

4.1 Starting off with Triangulation First increases students' inquisitiveness

In [14] we presented the triangulation first pedagogy with the following elements.

1. Using the DOT-framework as a basis, we favour a practical and pluralistic view of research.
2. A mixed-methods approach is advocated for solving real world problems.
3 At the start of the curriculum: choose to nurture an open minded research attitude over teaching specific methods; choose to build experience over knowledge and example based knowledge over rule-based knowledge (like research prescriptions).
4. In the later stages of the curriculum, all research is taught with reference to the DOT-framework.

In our institute the communication propaedeutic adopted the first three elements of this approach and research was *concentrated* in one course of 7, 5 EC (see [14] for details). The information technology propaedeutic did not adopt this approach but favoured a *distributed* approach, where elements of the DOT-framework were taught across several courses of the propaedeutic. Comparing inquisitiveness of information technology students at the beginning and at the end of the propaedeutic phase can thus give some insights into the effectiveness of the triangulation first approach.

Table 1. Comparing Inquisitiveness among propaedeutic student

	Communication Design	Information Technology
Start	N(63) Inq: 3.14	N(68) Inq:3.14
End	N(51) Inq: 3.38	N(56) Inq:3.10

Table 1 lists the results of our student questionnaire at the beginning and at the end of the propaedeutic phase of the studies for both groups. The start and end groups consist of different cohorts and were tested in a different period of the year. A One-Way Anova with LSD post-hoc test was performed to obtain significance levels for the differences in this table. The results show there is no significant difference between communication design students and information technology students at the beginning of the propaedeutic phase. However at the end of the propaedeutic communication design students score higher than at the beginning (p=0.05) and significantly higher than Information Technology students at the end of the propaedeutic phase (p=0.02).

In our view the most likely explanation is the difference in approach to teaching research; in particular the concentrated attention for research in one of the courses of the communication propaedeutic, although an alternative explanation could be that inquisitiveness plays a bigger role in all courses in the communication propaedeutic.

4.2 Teaching the DOT-Framework increases students' inquisitiveness

The triangulation first pedagogy suggests teaching research with reference to the DOT-framework throughout the research curriculum (point 4). Our investigation of learning materials and interviews has shown that this approach is adopted in many ways. Some of the majors use a concentric approach, thus using the DOT-framework in each semester, while others teach it only once, effectively not adhering to triangulation first. There is also variation in the vigour with which the framework is taught. Some teachers are enthusiastic and give the framework a prominent place in their lessons where others teach it more as a matter of duty. To get a course-grained indication whether teaching the DOT-framework was effective regardless of the didactic approach, we asked students whether they knew the framework. Students could answer they were unaware (3%), they had 'seen the picture sometimes' (20%) or it 'had been taught' (77%). For convenience we compiled 'unaware' and 'seen the picture sometimes' in a single category: not treated. Table 2 compares the inquisitiveness of these students.

Table 2. Inquisitiveness of students who claimed they were taught the DOT-Framework and those who claimed they weren't

	N	Inquisitiveness
Not treated	85	3.26
Treated	277	3.46

The results show that students who claim that the DOT-Framework has been treated have a significantly higher score on the inquisitiveness questionnaire (one-way Anova, p=0.02). Further analysis showed also that the confidence scores students gave about their ability to work with the DOT-Framework correlated positively with their inquisitiveness scores (Linear regression, $\beta=0.345$, $p<0.01$). Possible confounding variables were educational programme (communication design or software engineering) and length of study, but the effect of the DOT-framework existed independently of these variables. We were unable to test whether the DOT-framework specifically or research education in general explained the growth in inquisitiveness better, as most of our research education was using the DOT-Framework one way or the other.

4.3 Overall, there is a ceiling effect for inquisitiveness in our programmes.

Our general expectation was that inquisitiveness would grow during the programme. However, Table 3 shows this is not always the case.

Table 3. Comparison of inquisitiveness scores in both programmes

	Communication Design		Information Technology	
	N	Inquisitiveness	N	Inquisitiveness
Start 1st Year	63	3.14	68	3.14
End 1st Year	51	3.38	56	3.10
End 2nd Year	96	3.43	63	3.32
End 3rd Year	40	3.35	47	3.31

As we discussed, communication design students show more growth of inquisitiveness in the first year than information technology students, but this growth does also occur in the second year of the information technology programme. Neither information technology nor communication design students show much growth in the third year. This last finding is surprising because we would expect a general growth of inquisitiveness simply because of following higher education for a longer time and we would specifically expect it to grow since in the third year more time is reserved for research education (7,5 EC, rather than 2,5 EC).

One explanation for this ceiling effect is that, since the standards for research grow in the 3^{rd} year, students become more modest. When the awareness of their limitations grows they may be *reporting* lower inquisitiveness, while *demonstrating* higher inquisitiveness. This is not in line with findings by others, however, who do report growth of inquisitiveness in the later years [8]. Another explanation is that the ‘level’ of research education in the third year is not much higher than in the first and second year. This hypothesis is corroborated by our analysis of teaching materials in the third year. Most of these were fairly introductory, while those teams taught more in-depth lessons did show a rise in inquisitiveness in the third year. For this part of the curriculum, it may not have been the best choice to ask general staff, rather than specifically trained staff, to teach the research lessons.

4.4 Mixed-didactics support nurturing inquisitiveness

Since teaching research topics is beneficial for the development of inquisitiveness among students, we wondered what didactics were most appropriate. Based on our inspection of teaching materials and interviews with teacher teams we distinguished between three approaches roughly based on the amount of supervision and guidance by teachers.

With *teacher-led* didactics we refer to approaches where teachers explain the theory behind doing research and provide targeted exercises for students to practice this theory. With *master-apprentice* we refer to a didactic model where students are asked to carry out an open-ended research exercise with some complexity and teachers actively seek out to support student development of research skills [9]. Finally in *unsupervised learning* students are asked to complete an open-ended research exercise without much support. We also encoded to what extent teachers adopted a variation of different didactic approaches. Although teacher-led education is more effective than the other approaches for developing knowledge and skills in general, it is arguable that research education forms an exception. Inquisitiveness requires an independent attitude from the students and open ended problems. Following this line of reasoning one could argue the master-apprentice and unsupervised learning didactics are also essential in design research education.

To settle which students were subject to what didactics we set up a coding scheme including the distinction between these three didactic approaches. As research team we decided upon the didactics for each educational unit and provided sheets enlisting these findings. Next we performed a member-check, sending our findings for revision to the teaching teams. Adjusted versions of the sheets were then coded into numbers by a fixed scheme: all ratings were done by two raters who showed excellent agreement (Cohen’s Kappa 0.90). The results of the coding were correlated to inquisitiveness using linear regression. Table 4 lists the results.

Table 4. Influence of didactics on inquisitiveness

	β	P
Teacher-led	0.114	0.07
Master-Apprentice	0.096	0.14
Unsupervised	-0.063	0.35
Variation of Approach	0.134	0.04

The effects found for each didactic approach are modest at best (with all $\beta<0.12$). Within this set, a varied approach is significantly more effective in nurturing inquisitiveness, whereas from the individual approaches teacher-led shows the strongest effect followed by master-apprentice didactics. Unsupervised learning showed no, if not negative, effects on inquisitiveness. These results suggest that a mixed didactic of teacher-led with master-apprentice elements is probably best to strengthen students’ inquisitiveness. This is in line with the theoretical notion that teacher-led didactics generally strengthen students’ learning and to a lesser extent with the argument that students need a fair amount of freedom and independence to nurture inquisitiveness.

We also coded how students were tested on research. This could be through explicit research documents or integrated in other deliverables. Correlating those expert scores with inquisitiveness revealed explicit testing had a modest positive effect on students’ inquisitiveness ($\beta=1.40$, $p=0.03$).

5 CONCLUSION & DISCUSSION

In this paper we discussed the effects of integrating research education within professionally oriented design and engineering programmes, using inquisitiveness as the central outcome measure. We were especially interested in the effectiveness of the triangulation first pedagogy [14] and the DOT-framework [14,15] as means to achieve such an integrated research programme. We found them effective for increasing students' inquisitiveness; be it mainly in the early stage of our programme. Inquisitiveness turned out to reach a ceiling effect in the third year. This could be due to the lack of available didactic materials tailored for in-depth research lessons - as majors who already developed such materials escaped the ceiling effect. Our investigation into didactics showed teacher-led and master-apprentice to be good approaches to teach research, in particular when used in combination, while unsupervised learning showed to be ineffective.

Despite the positive indication this study gives for the triangulation first approach, it is hard to address this question independently of the implementation in the organization. The interview and document study revealed a diversity of interpretations and didactic uses of the DOT-framework, highlighting that the differences between the curriculum as intended by us and the curriculum as it was executed by teachers were substantial. We also found frequent discrepancies between the teachers and the student's perception of the curriculum. Such differences are common [11], but it means that implementation of the curriculum bees attention. Teachers need to have access to the right teaching materials and be fluent in the proposed didactic approaches, to be able to adopt an approach like triangulation first.

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