# The Pervasive, Embedded, and Mobile Computing Curriculum – Preparing Computer Science Students for the Technology of the Future

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## ABSTRACT

This IE Curriculum Award 2012 application describes the Danish Pervasive, Embedded, and Mobile Computing Curriculum – or just Pervasive Computing Curriculum for short. This curriculum is currently being taught at the IT University of Copenhagen (ITU), but have been developed and refined since 2003 where it was inaugurated at the University of Aarhus. The curriculum consists of four main parts; (i) a pervasive computing course that introduces graduate students to theoretical and technological aspects of pervasive, mobile, and embedded computing; (ii) a pervasive computing project where students identify and solve real-world problems using state-of-the-art pervasive computing technologies and concepts; (iii) a Master of Science (MSc) thesis program which allow students to pursue a specialization within pervasive computing for their graduation; and (iv) an PhD program and course that introduces and guide PhD students within pervasive computing.

The practical, technological part of building pervasive computing systems and applications takes place in the Pervasive Interaction Technology Laboratory (PIT lab), which has plenty of hardware resources for the students' projects. Regular project presentations are done at ITU, where students show off their project – often a fun experience for all.

All teaching and curriculum material is widely available for public reuse, including course blogs, recommended reading lists, lectures, slides, lab classes, assignments, project proposals, former student projects for inspiration, video, and pictures. The curriculum development has contributed to two text book on pervasive computing topics, which are used in the teaching of the course. The PhD course and the associated 'Fish Model' is given at international PhD school events, like doctoral colloquiums at conferences.

The pervasive computing curriculum has had significant impact on Danish academia and industry. In the 9 years the courses has been taught, more than 200 graduate students has passed the course; more than 50 pervasive computing projects have been made; 11 MSc. thesis projects have been done; and more than 3,000 ETCS points has been 'produced'. Moreover, the overall satisfaction with the course from the students viewpoint is very good; in average 5.31 on a scale from 1–6.

Nine pervasive computing students have pursued academic careers within pervasive computing, and have been active in the Pervasive and Ubicomp scientific community. Based on their research on pervasive computing technologies for hospitals, some of these students have founded the company Cetrea A/S. This company is based on the research done in the 'Interactive Hospital' project, and now employees 40 persons and sells its solutions to customers in Denmark, Norway, Sweden, Germany, and the US.

## INTRODUCTION

Pervasive computing[1] has become a core academic research area within the last decade. At the core, pervasive computing denotes a vision of small, inexpensive, robust networked processing devices, distributed at all scales throughout everyday life that servers different application areas. Typically application areas are targeted 'everyday life' scenarios like personal health, domestic living, traveling, energy-aware resource consumption, and games. This kind of embedded, mobile, and pervasive computing technologies are increasingly playing a greater and greater role in society; the number of smartphone apps are exploding, and many of them are exploiting their build-in location tracing technology.

Pervasive computing embrace mobile and embedded computing, as many pervasive computing platform and technologies are mobile or embedded in the artifacts of everyday life [12]. For example, modern smartphones are a common platform for e.g. pervasive health applications [4], and embedded sensors in operating rooms may help improve patient safety in hospitals [9]. For a computer science and/or electrical engineering tertiary teaching institution it is therefore essential to offer education within pervasive, mobile, and embedded computing. Computer science students will need the theoretical and practical skills that are necessary to build these kinds of systems in the future.

[1]Pervasive computing is also described as ubiquitous computing (ubicomp), ambient intelligence, or, more recently, everyware.

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This paper describes a Pervasive Computing Curriculum aimed at teaching pervasive, embedded, and mobile computing for graduate computer science students. The curriculum was inaugurated in 2003 and has been continuously refined since, and has been taught at two Danish universities. The curriculum consists of four main components:

**Pervasive Computing Course** – The main lecturing component in the curriculum is the pervasive computing course. This is a one semester, 7.5 ETCS point course covering major topics within mobile, pervasive, and embedded computing from a conceptual/theoretical as well as technological/practical stance.

**Pervasive Computing Project** – The pervasive computing project is a one semester, 7.5 ETCS project in which students are required to formulate a problem, design a solution, implement it, and make a limited evaluation of it.

**Pervasive Computing MSc Thesis** – The pervasive computing Master of Science (MSc.) thesis program is a full semester (30 ETCS) project where the students analyze a real-world problem, and propose, design, implement, and evaluate a technical solution.

**Pervasive Computing PhD Course** – The pervasive computing PhD course is a general-purpose course, which teaches newly admitted PhD students how to do a PhD within the research tradition and community of Pervasive and Ubiquitous Computing. The course focuses on important milestones, activities, research methodologies, and communities/conferences.

This pervasive computing curriculum is supported by a wide range of teaching material, which is available for public use; all of the lecture slides and notes, the tech talks, the lab classes, the exercises, the project reports, etc. are all available from a web page for others to reuse or be inspired from[2]. All parts of the curriculum is prepared and taught in English due to the large amount of foreign students in Denmark, as well as to ensure international sharing and reuse of the material. Moreover, as part of maturing teaching material for the pervasive computing course, we have contributed to a text book on 'ubiquitous computing fundamentals' [1], and we have edited and published a specialized text book on pervasive healthcare applications and research [7].

Since the pervasive computing curriculum was inaugurated in 2003, more than 200 students have graduated from two universities. Several of these students have subsequently done a PhD degree in pervasive computing, and are today successfully pursuing scientific and industrial careers.

## THE PERVASIVE COMPUTING COURSE

The Pervasive Computing Course has been developed and refined over 9 years. The first edition of the course was taught in the fall semester of 2003 at the University of Aarhus and the latest edition is currently running in the spring semester of 2012 at the IT University of Copenhagen. The course has always had two main components:

[2] http://www.itu.dk/people/bardram/pmwiki/?n=Main.Teaching

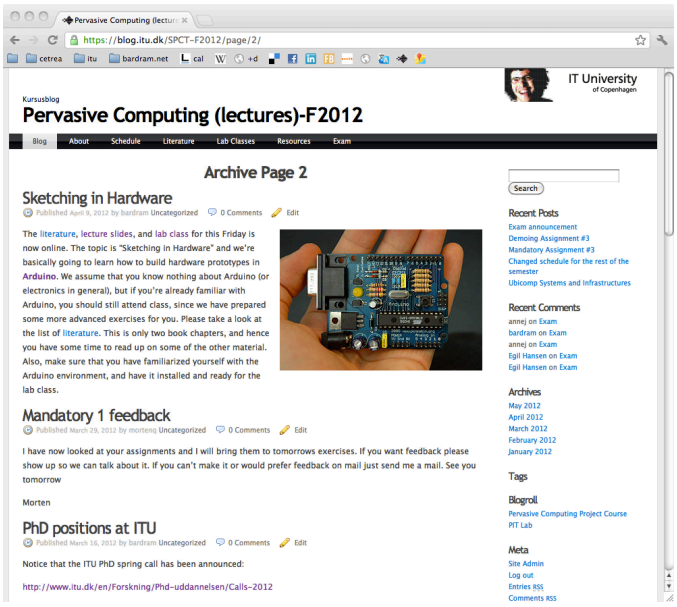


**Figure 1. The course blog of the "Pervasive Computing Course" at the IT University of Copenhagen. This is from the spring 2012 edition of the course.**

- A *theoretical and conceptual introduction* into core pervasive and mobile computing concepts, approaches, technologies, and architectures.
- *Laboratory classes* with concrete hands-on experience with specific technologies, frameworks, programming APIs, and hardware.

The course consists a significant amount of work for the students, and successfully passing it will earn them 7.5 ETCS points, equal to one quarter the workload of a semester.

The intended learning outcome [10] of the 'lecture' course is officially stated in the ITU course base as:

*"After completing the course, students are expected to be able to:*

- *describe the background, vision and the most important application areas of Pervasive Computing,*
- *be able to explain and use the core concepts and technologies within location-based services and context-aware computing,*
- *explain the principles of different pervasive computing architectures and infrastructures including service discovery and wireless communication,*
- *explain and use different new types of user interfaces including tangible, embedded and wearable interaction,*
- *explain and use different types of sensor technology and data processing approaches,*
- *explain and use different activity recognition methods,*
- *explain and use principles of mixed-reality models and tagging technologies."*

Students admitted to the course are graduate students having a bachelor degree in computer science, electrical and software engineering, or similar. It is a prerequisite for entering the pervasive computing program that students have taken courses on distributed computing, operating systems programming, and theoretical computer science. Moreover, it is highly recommended that students have taken coursework in human-computer interaction.

As shown in Figure 1, the course runs an elaborate course homepage which has; (i) a blog for communication between students and lectures; (ii) a description of the course and its requirements; (iii) the schedule of the course; (iv) the list of literature for the course; (v) the list of lab classes including mandatory assignments, (vi) a list of resources available 'out there' on the web; and (vii) a description of the exam. The course home page runs on top of a WordPress blog systems and has elaborate features for blogging, commenting, etc. for the students to engage in the course. For this reason, no email are used at all in the course – all communication uses the course blog for all students to share.

The teaching activities of the pervasive computing course consists of three main parts, which runs weekly:

- A three-hour *Lecture* where core theoretical and technological concepts, approaches, and applications are presented
- A one-hour *Tech Talk*, where a specific technology is introduced to the students.
- A three-hour *Lab Classes*, where students solve specific exercises typically using the technology introduced in the tech talk.

The course covers different *topics*, each organized in different *blocks*[3]:

- Introduction to Mobile, Pervasive, & Embedded Computing
- BLOCK I – MOBILE & CONTEXT-AWARE COMPUTING
  - Mobile Computing
  - Location Technologies & Location-based Services
  - Context-Aware Computing.
  - Ubiquitous Computing Applications, with focus on healthcare, environmental, & game applications.
- BLOCK II – DESIGNING UBICOMP SYSTEMS
  - Design, Prototyping, & Evaluation Methods.
  - Tagging Technologies.
  - Surface & Tangible Computing
  - Mixed Reality Computing.
- BLOCK III – EMBEDDED SYSTEMS AND INFRASTRUCTURES
  - Embedded Computing & Hardware Building
  - Systems & Infrastructures
- BLOCK IV – SENSORS, DATA, & ANALYSIS
  - Sensors & Sensor Networks
  - Data Processing
  - Data Analysis & Activity Recognition.

[3]The course schedule for the 2012 edition of the course can be seen at `https://blog.itu.dk/SPCT-F2012/schedule/`

Each topic is covered in lectures, tech talks, and lab classes. As an example let us look at the topic on 'Mobile Computing'. The *lecture* covers issues like challenges in mobile computing (e.g., volatile systems environment), different mobile computing approaches and technologies (e.g., service discovery and stateless communication protocols), and security & privacy in mobile computing. The *tech talk* teaches the students about the Android OS, its architecture, and how to program the Android platform. In the following *lab class*, the students are asked to write some simple Android applications using wireless communication and multithreading in Android, and experiment with deployment of these apps. Throughout the rest of the course, the Android platform is used as a the main computing platform in the lab classes. For example, one lab class asks students to build a cloud-based infrastructure for sensor data management using the Android phone as the sensor client, and in another lab class the students are asked to develop an activity recognition system, which can recognize activities like walking, sitting, running, etc. based on the Android phone sensors.

Courses at ITU are subject to a yearly course evaluation by students. In these evaluations, the pervasive computing course in general scores very high. In the evaluation, the students are asked several questions, and asked to score the different aspects of the course on a 1–6 scale: 1 is 'I completely disagree' and 6 is 'I completely agree'. On the concluding question of *"Overall conclusion: I am happy about this course"*, the pervasive computing course has scored 5.05; 5.56; and 5.33 in 2010, 2011, and 2012 respectively. This is in average 5.31, which is one of the highest rated courses at ITU.

During the evaluation, the students can write feedback and comments on good and negative parts of the course. The main positive feedback reveals that students really like the combination of theoretical lectures and the practical tech talks and lab classes. The negative feedback consistently reveals that students find that the course requires too much work, especially in terms of reading scientific literature and in terms of implementing lab classes and mandatory assignments. The course is, however, intended to be rather demanding on the students; we aim high on behalf of our students.

## THE PERVASIVE COMPUTING PROJECT

The purpose of the Pervasive Computing Project is to allow the students to do a larger pervasive computing project on a specific topic.

It is required that students have passed, or are concurrently following the pervasive computing course. In this way, the course and the project parts are designed to be very flexible to accommodate different study programs that students may have. This allows students to focus on the theoretical and practical activities in the course in one semester (the spring) and then do the project in the coming (fall) semester.

The intended learning outcome [10] of this project part of the curriculum is officially stated in the ITU course base as:

**Figure 2. The 'PourImages' project, where users can share images from their Anroid phone by just 'pouring' them out on a shared tabletop displays, situated in the public student café at ITU.**

*"After completing the course, students are expected to be able to:*

- *construct large, usable pervasive computing systems (app. 10.000 lines of code) including being able to analyze a problem, suggest software and hardware architecture, a system design, implement the design, and evaluating it.*
- *document the developed pervasive computing system in a paper using the elements you will normally find in an ACM Ubicomp conference paper.*

The students can select from a predefined set of project suggestions or they can form their own project description, for example together with a company or a public organization. The topic of the project can be anything within pervasive, mobile and embedded computing, but should involve theoretical topics covered by in the lectures.

In order to help the students do a good project, as series of small two-hour lectures are given during the semester, as outlined below:

- *Introduction* to the Pervasive Computing project
- *Defining* your Pervasive Computing project
- *Designing* your Pervasive Computing prototype
- *Implementing* your Pervasive Computing project
- *Evaluating* your Pervasive Computing prototype
- *Documenting* your Pervasive Computing project

It is required that a project; (i) formulates a real-world problem statement; (ii) surveys relevant related work; (iii) contains a technical implementation of either a basic technology or an application; (iv) does an evaluation of the implemented technology or system; (v) documents the project as an paper formatted as a conference paper for the Ubicomp conference series.

A wide range of projects have been done over the year, including;

- Indoor location estimation using Bluetooth (2003)
- Context-awareness in the Bang & Olufsen home (2004)
- PourImages – An Interactive System for Sharing Images (2010)[4]
- An Ad-hoc Network of Android Phones Using BATMAN (2010)[5]
- NOxDroid – A Wearable environmental sensor and feedback system (2011)[6]
- A Wearable Kids' Health Monitoring System (2012)[7]
- Smart Home infrastructure for easy deployment and service discovery (2012)[8]

This list illustrates the breadth of the types of projects done in the project part of the curriculum. For example, the 'PourImages' project developed a shared tabletop application for sharing pictures in the student café at ITU as shown in Figure 2, whereas the 'Smart Home Infrastructure' project developed an infrastructure for easy deployment, discovery, and configuration of smart home devices like light switches, temperature controller, etc., as shown in Figure 3. Other projects take their outset in problems defined by industrial or public partners. For example, a project looking into making home HiFi systems context-aware has been done with Bang & Olufsen, and a project on creating an embedded monitor system for kids in kindergardens has been done together with a general practitioner (GP), kinder garden pedagogues, and parents to kids in the age of 3-4 years.

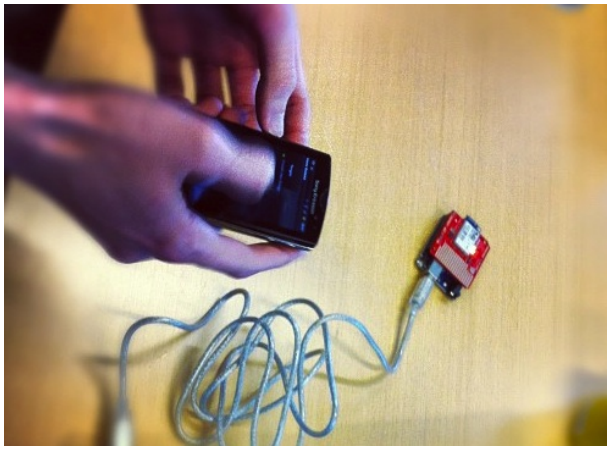

**Figure 3. The 'Smart Home Infrastructure' project, where embedded controllers for the home can be easily discovered and configured for a wireless home network using an Android smart phone app.**

When the project is done and handed in, the students present their project for each other and for other students that may be interested. This public event is often of great fun for the students, where they can show off their project to others. For example, Figure 4 shows the demonstration of the NOxDroid project that did an air pollution sensor for cyclists in Copenhagen. The NOx sensor was embedded in

[4] https://blog.itu.dk/SPVC-E2010/files/2011/08/10pourimages.pdf

[5] https://blog.itu.dk/SPVC-E2010/files/2011/08/13adhocandroid.pdf

[6] http://www.noxdroid.org/

[7] http://www.itu.dk/pit/?n=Projects.KidsHealthMonitoringSystem

[8] https://blog.itu.dk/SPCL-F2012/files/2012/06/5thingiesfordummies.pdf

**Figure 4. Demonstration the NOxDroid embedded sensor system for monitoring air polution while biking in Copenhagen.**

a old-fashioned bicycle light and was connected to the cyclist's Android phone, which then uploaded pollution data to a cloud-based infrastructure. When demonstrating the project, one student was biking around both inside ITU and outside of the building, while the audience followed the air pollution in Copenhagen live on a large screen.

In total more than 50 projects have been done over the years.

## THE PERVASIVE COMPUTING MASTER THESIS

Students at ITU is offered to do a Master of Science (MSc.) thesis within pervasive, embedded, and mobile computing. This MSc thesis finalizes their graduate studies within computer science and takes up full time during a semester (equivalent to 30 ETCS). The purpose of a master thesis is that the student(s) should analyze a real-world problem and come up with a technical solution and implementation that solved this problem. An evaluation is also required, and depending on the nature of the project, this evaluation can take different forms. If it is a technical project, focusing on e.g. a new communication protocol, the evaluation is technical in nature and seeks to gauge the technical feasibility and performance of the technology proposed. If it is a pervasive computing application, such as a personal health system, a more user-centered design and evaluation methodology is appropriate.

Examples of MSc thesis projects done lately at ITU include:

- Embedded Context-Aware Safety Systems for the Operating Room [9]
- Context-Aware Public Display for Activity-Based Computing in Hospitals [2]
- Phase Recognition in an Operating Room using Embedded and Wearable Sensor Technology [3]
- Using Device Composition on Tabletop Computers to Extend the Smartphone Experience
- Non-anonymous User Interaction on Tabletop Displays

**Figure 5. Evaluating the automated phase recognition system having surgeons performing simulated surgery in a surgical simulation facility.**

The aim of the MSc thesis is that it addresses a real-world problem and this should be done in cooperation with an external partner. This can be an industrial partner, or a public organization, like a hospital. The scientific ambition of a MSc thesis is to situate the work within research at an international level. It is not required that there is a scientific contribution, but that the project can formulate a proper motivation and problem statement, and relate the solution to existing solutions in the literature. Sometimes the student(s) has an ambition that their project can be published in an international peer-reviewed conference or journal. This ambition is sometimes achieved, as can be seen from the list above, which include publications at core pervasive computing conferences like Ubicomp and PerCom. For example, the project on 'Phase Recognition in an Operating Room using Embedded and Wearable Sensor Technology' has ben published in the IEEE PerCom 2011 conference [3]. Figure 5 shows a picture from the evaluation of the system done together with surgeons performing simulated surgeries in a surgical simulation lab at the University Hospital of Copenhagen.

All of these MSc thesis's are available from the Pervasive Interaction Technology (PIT) lab homepage, including the thesis report itself, and additional resources like sensor data sets, source code, test results, images, and videos[9].

## THE "THE ART OF DOING A PHD" COURSE

As students started to pursue a PhD degree within Pervasive Computing, a need for a more dedicated PhD course emerged. Based on years of experience in supervising PhD students within computer science and ubiquitous computing, we developed, and are constantly refining, the "The Art of Doing a PhD" course. This course is used to introduce new PhD students at ITU, but has also been given at international doctoral consortiums and PhD Schools, including:

- The Doctoral Colloquium at the *UbiComp 2007 Conference* in Innsbruck, Austria.

[9] http://www.itu.dk/pit/?n=Main.PreviousProjects

- The Doctoral Colloquium at the *Pervasive 2009 Conference* in Nara, Japan.
- The *Marie Currie European Research and Training Network* 2011 PhD School Event at the University of Passau, Germany.

The core conceptual model used in this course is the co-called 'Fish Model' as shown in Figure 6. Without going into too much details here, the fish model basically illustrates the timeline of a PhD project along the horizontal line, and a division between 'theoretical' work and 'empirical' work along the vertical line. Along the timeline, the figure illustrates that in the first 1/3 of a PhD you need to be 'open minded' and investigate existing and new ideas both from a theoretical and empirical stance. But once you reach the '1/3 deadline', it is crucial that the student stops being open minded, and starts working focused towards his or her specific project, and contributions – again simultaneously in a theoretical and empirical manner. The 'tail' of the fish illustrates the writing of the thesis, which again has a theoretical part (i.e., writing the thesis) and an empirical part (i.e., making sure that data, source code, hardware blueprints, etc. are available for others to access).

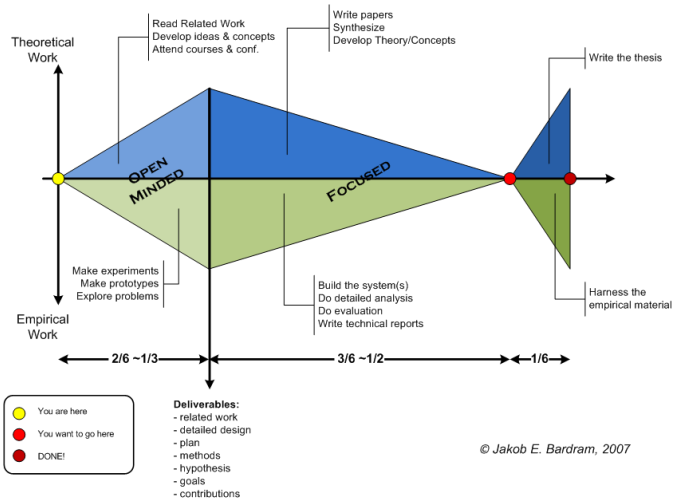


**Figure 6. The 'Fish' model, illustrating the timeline of a typical pervasive computing PhD. The upper (blue) part represents 'theoretical' work, whereas the lower part represents 'empirical' work.**

The lecture and slides on "The Art of Doing a PhD" have been available for general use from slideshare.net since 2007[10]. At slideshare the slides has been viewed by more than 10,000 users, has been embedded on more than 700 other webpages, and has been 'favorited' by more than 40 students. The model and the slides is also available online for others to (re)use[11].

## TEACHING MATERIAL

As stated above, the teaching material from the different parts of the Pervasive Computing curriculum is widely available for reuse and inspiration by others. Table 1 provides an overview of the different teaching material available.


**Figure 7. The 'Pervasive Computing in Healthcare' and the 'Ubiquitous Computing Fundamentals' text books used in the pervasive computing curriculum.**

In 2009, John Krumm from Microsoft Research identified the need for a new and comprehensive text book, which could be used in pervasive and ubiquitous computing teaching. He therefore invited a set of core pervasive computing researchers and lectures to help write an edited book on 'Ubiquitous Computing Fundamentals'. Having the more technical focus on teaching embedded and mobile pervasive computing systems, we contributed to the book chapter on 'Ubiquitous Computing Systems' together with Adrian Friday from Lancaster University [1]. The book was published in 2010, and is used as the main text book in the Pervasive Computing Curriculum at ITU, as well as in other pervasive computing courses internationally[12].

In addition, a more specialized text book on pervasive healthcare applications and research has been put together in order to provide a more accessible text book for students and teacher on this rather important sub-field of pervasive computing [7]. The two books are shown in Figure 7.

## LABORATORY FACILITIES

An important resource in the pervasive computing curriculum is the Pervasive Interaction Technology Laboratory (PIT lab)[13], which manage all the technologies needed for doing lab classes, projects, MSc thesis's, and PhD projects within pervasive computing.

The PIT lab has a wide range of hardware resources for the students to use, including indoor location tracking systems (e.g., Ubisense and a Bluetooth-based system); numerous Arduino class kits with all sorts of additional sensors and actuators; various RFID technologies (active/passive, and HF/UHF RFID technology); wall-based multi-touch displays;

[10] http://www.slideshare.net/bardram/the-art-of-doing-a-phd
[11] http://www.itu.dk/people/bardram/pmwiki/?n=Main.ArtPhD
[12] The book is, for example, used at Carnegie Mellon University and Bauhaus-Universität Weimar.
[13] http://pit.itu.dk/

| *Curriculum Component* | *URL* |
|---|---|
| Curriculum Overview | `http://www.itu.dk/people/bardram/pmwiki/?n=Main.Teaching` |
| 2012 Course Blog | `https://blog.itu.dk/SPCT-F2012/` |
| ... Lectures | `https://blog.itu.dk/SPCT-F2012/schedule/` |
| ... Literature | `https://blog.itu.dk/SPCT-F2012/literature/` |
| ... Lab Classes | `https://blog.itu.dk/SPCT-F2012/lab-classes/` |
| 2012 Project Blog | `https://blog.itu.dk/SPCL-F2012/` |
| ... Lectures | `https://blog.itu.dk/SPCL-F2012/schedule/` |
| ... Proposals | `https://blog.itu.dk/SPCL-F2012/proposals/` |
| PIT Lab | `http://pit.itu.dk/` |
| MSc Thesis | `http://www.itu.dk/pit/?n=Main.PreviousProjects` |
| PhD Course | `http://www.itu.dk/people/bardram/pmwiki/?n=Main.ArtPhD` |
| The Art of ... | `http://www.slideshare.net/bardram/the-art-of-doing-a-phd` |

**Table 1. Overview of teaching material for the pervasive, embedded, and mobile curriculum.**

**Figure 8. A student building an embedded proximity sensor in the PIT lab, which was used in the GridOrbit Display System.**

tabletop displays (e.g., the Microsoft Surface 1.0/2.0); sensor networks (e.g., the Libelium Waspmote Sensor Kits with a variety of sensors and communication modules for Bluetooth, WiFi, Zigbee, GPRS, and GPS); several Android-based smartphones and tablets; and many other things. Figure 8 shows a student in the PIT lab soldering an embedded system for proximity detection used in the GridOrbit Display System [11].

## IMPACT

As outlined above, the Danish pervasive, embedded, and mobile computing curriculum have had some impact on the education of computer scientists at the University of Aarhus and at the IT University of Copenhagen. Table 2 summarizes the impact over the years. The figures in Table 2 should be judged relatively to the size of the Danish computer science community. For example, it is estimated that ca. 7,500 computer scientists have been educated in total in Denmark since 1970. This means that since 2003, ca. 3% of these has followed the pervasive computing course. Another way to look at it is, that ITU educates ca. 70 computer science graduates each year, of which ca. 40% take the pervasive computing course.

| *Parameter* | *#* | *Note* |
|---|---|---|
| Years running the course | 9 | AU & ITU |
| No. grad. students | +200 | |
| No. projects | +50 | |
| No. MSc Thesis | 11 | AU & ITU |
| No. ETCS produced | +3,000 | |
| Average eval. score (ITU) | 5.31 | 1–6, 6 is best |

**Table 2. Impact of the Pervasive Computing course in terms of # students, # projects, # ETCS, and average scores in course evaluation.**

### Scientific Impact

One indicator of the scientific impact of the pervasive computing curriculum is the number of students, who has been part of the curriculum and who has pursued an academic career within pervasive computing afterwards[14]. Here we can identify nine (year in parenthesis is graduation year):

- Thomas Riisgaard Hansen (2006) – CTO at Cetrea A/S.
- Martin Mogensen (2008) – chief architect at Cetrea A/S.
- Jonathan Bunde-Pedersen (2008) – chief architect at Cetrea A/S.
- Mikkel Baun Kjægaard (2008) – former post doc at ETH Zürich; now post doc at the University of Aarhus.
- Jepppe Brønsted (2007) – lead developer at Cetrea A/S.
- Clemens N. Klokmose (2009) – post doc at INRIA, Paris Sud, and the University of Aarhus.
- Frank Allan Hansen (2007) – former post doc at the University of Aarhus, now research scientist at the Alexandra Research Institute.
- Jacob Andersen (2008) – research scientist at the Alexandra Research Institute, Denmark.
- Morten Esbensen (ongoing)

Another indicator of scientific impact is the number of papers published by students, who has been part of the pervasive computing curriculum. This cannot be measured completely accurately, but by just adding the publication lists of the people listed above plus the number of MSc. thesis's that

[14]By 'academic career' we mean pursuing a PhD degree.

has been published as papers, the total number surpasses 100 papers.

### Industrial Impact

Most of the students graduated from the pervasive computing curriculum are now working in the Danish ICT industry, including internationally well-know companies like Bang & Olufson, Vestas, and Radiometer (part of the US-based Danaher Corporation).

Some of the students listed above have formed the company Cetrea A/S[15], which explicitly aims at developing and selling pervasive computing technologies for use in hospitals. The company is based on research done as part of their PhD studies in the co-called 'Interactive Hospital' project [6, 5, 8], and as such builds directly on the pervasive computing curriculum. Cetrea now employs ca. 40 persons of which half are computer scientists. Cetrea develops pervasive computing technologies for clinical logistics, and is marketing and selling its products in Denmark, Norway, Sweden, Germany and the US.

## LETTERS OF SUPPORT

With this application, two letters of support are included:

1. *Jens Christian Godskesen*, Head of the Research Department at the IT University of Copenhagen. This letter addresses the impact of on the development of the pervasive computing curriculum at ITU.

2. *Tom Togsverd*, Director of the Danish ICT and Electronic Federation and the Confederation of Danish Industry. This letter from the main industrial ICT organization in Denmark addresses the impact of the teaching in pervasive computing on industrial and societal affairs.

## CONCLUSION

This paper has described the Pervasive, Embedded, and Mobile Computing curriculum currently being taught at the IT University of Copenhagen. The curriculum was originally inaugurated in 2003 at the University of Aarhus, and has been refined and improved since. By now, the curriculum consists of a comprehensive set of teaching activities, materials, and lab facilities that supports pervasive computing education on a graduate, master of science, and PhD computer science level. Through systematic course evaluations, we know that students are very satisfied with the courses – scoring 5.31 out of 6 in average.

Relative to the size of the computer science community in Denmark, the curriculum has had significant impact; more than 200 graduate students have followed and passed the course; more than 50 pervasive computing projects have been done; 11 MSc. thesis's have be made and some of these has been published in peer-reviewed pervasive computing conferences; and 9 of these students have pursued an academic career within pervasive computing. Some of these students are now academics at different universities or research institutions, while other have founded a company. Today, almost 40% of all ITU computer science students take the course.

The teaching material from the pervasive computing curriculum is widely available on the web for others to reuse and take inspiration from. We are happy to share our material for the greater academic community within pervasive computing, and also gladly help other academic institutions to set up a curriculum in pervasive, embedded, and mobile computing.

[15] http://www.cetrea.com/

## ACKNOWLEDGMENTS

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