TEACHING AN INTEGRATED NEW PRODUCT DEVELOPMENT SEMINAR ON COGNITIVE PRODUCTS

K. Shea, M. Engelhard, B. Helms and M. Merz

Keywords: cognitive products, cognitive technical systems, project-based learning, new product development, design teaching

1. Introduction

While research areas become more specialized every day, interdisciplinary research and teaching become more important to develop new synergies across disciplines. The benefits of interdisciplinary teaching are numerous including preparing students to think and work across traditional discipline boundaries, to appreciate knowledge of other disciplines, to communicate with people from other disciplines and to see how disciplines can be integrated to produce something that is greater than their sum. A classic example is the integration of electronic and mechanical components together with software to create mechatronic devices. A recent example is the goal of researchers in the fields of artificial intelligence, robotics, psychology, neurology and engineering to create cognitive technical systems (Beetz et al., 2007).

To address this new and promising area, the research cluster, “Cognition for Technical Systems” (CoTeSys) has been established at the Technical University of Munich (TUM). The cluster includes the following research areas: (1) neurobiological and cognitive foundations, (2) perception, model acquisition, and diagnosis, (3) learning and knowledge, (4) action, planning, and joint action, (5) human interaction and (6) demonstration scenarios. To build the bridge from research to education, the new product development seminar, “Innovation@CoTeSys”, described in this paper, has been established. While the demonstration scenarios consist of large-scale projects, e.g. cognitive factory, cognitive humanoid robot and cognitive vehicles, the seminar explores the potential of embedded cognitive capabilities to drive the next generation of consumer products. The main goal of the seminar is educational and aims to provide students with experience in artificial cognitive systems and related technology, developing new products, prototyping and working in multidisciplinary teams. A further goal is to motivate student interest in becoming PhD students in the research cluster. Through close collaboration with industry and UnternehmerTUM, the center for entrepreneurship at TUM, the seminar provides the potential for students to work with industry or establish start-up companies around their new products thus bringing the ideas of the research cluster to industry and society.

The seminar is a main educational component of the CoTeSys research cluster. It is founded on project-based learning (PBL) and learning by doing, as an alternative to the more typical separation between lectures and hands-on practical work found at TUM. Project-based learning is the current preferred model for teaching engineering design in the US (Dym et al., 2005). The focus of the seminar is around cognitive products, or the product, rather than as a means to teach design methods and product development processes alone. However, to support successful development of new cognitive products, the seminar employs a user-centered, integrated and methodical process. The unique challenges in setting up this seminar include providing students with enough technical background to understand and imagine what cognitive products could be as well as taking the students through a process that emphasizes both idea generation and hardware and software prototyping.

Three different approaches to teaching and getting students involved in research have influenced the formation of this seminar, namely student robotics projects, integrated design projects and undergraduate research projects. Undergraduate student projects in areas related to CoTeSys generally focus on robotics, commonly aimed at motivating and encouraging students through local, national or international competitions (Dodds et al., 2006). In such competitions the design task, requirements and constraints for the robot are well defined for all teams. In contrast, new product development projects are more open-ended in nature and include a focus on finding new product ideas and defining product requirements. For example, Carnegie Mellon's Integrated New Product Development (iNPD) combines teams of engineering, industrial design, and business students (Vogel et al., 1997) and often results in patentable products that are developed in collaboration with industry. Another comparable approach is MIT's Product Design and Development class, which is taught with combinations of business, engineering and industrial design students (Ulrich and Eppinger, 1995). Finally undergraduate research projects, such as MIT's Undergraduate Research Opportunities Program (UROP), which has inspired the SIROP network in Germany (TUM) and Switzerland (ETHZ, ZFH), enable students to get involved in research, investigate new areas of interest, and motivate good students to do PhDs and enter careers in research.

This paper starts with a brief introduction to cognitive technical systems and cognitive products. Next, the seminar process and infrastructure are explained. Results for the first two seminars are presented leading to a discussion of key findings and experiences.

2. Cognitive Technical Systems and Cognitive Products

This section gives a short overview of the area of cognitive technical systems (CTS) to describe the basis and requirements for the seminar. According to Brachman (2002) cognitive technical systems are systems, "that know what they're doing". Cognitive products are defined here as products that combine mechanical systems, electronics, microprocessors and embedded software and act in an increasingly intelligent, flexible and robust manner, as opposed to deterministic, static control of machines and mechatronic systems. Potential cognitive capabilities in products include environment and capability awareness, a high level of interaction with humans, machines and the environment, the ability to explain and reflect on actions, the ability to reason about and plan future actions and finally the ability to provide produce robust responses to unexpected situations. Taking the product lifecycle into consideration, cognitive products also exhibit improved performance and reliability over time by learning from experience, as humans do.

From an architectural point of view, following Beetz (Figure 1), cognitive technical systems perceive their environment using sensors and process this data using cognitive algorithms in order to plan and execute actions. Learning and reasoning as well as acquiring and updating knowledge models are key modules in such a system to move beyond deterministic response and achieve more purposeful response of products in unstructured environments. Paetzold (2007) describes integration of cognitive abilities into technical systems as the natural evolution of mechatronic systems and places importance on both a higher level of information processing and the physical embodiment of the system, including sensors and actuators as the main link to the environment.

According to these definitions there are very few products currently on the market that exhibit cognitive capabilities. Products that come closest stem from robotic applications. For example, the iRobot Roomba robotic vacuum cleaner (Jones, 2006) is used as a case study in the seminar. The Roomba is capable of autonomously vacuuming a house and returning to the base station when either finished or the battery level is low, exhibiting limited self-awareness. However, the Roomba contains no internal environment model and only detects that there is something in front of it, not what it is, and changes its path accordingly using various behavior-based programming methods, e.g. random bounce and wall following. It does not "know" what it is doing and can not respond well to surprise, e.g. find its way out from underneath a chair. Most autonomous robotic products, e.g. Robomow[1], exhibit

[1] *http://www.friendlyrobotics.com/*

similar capabilities. A product that comes closest to a cognitive product is the Wakamaru[2] from Japan. This is an autonomous service robot that acts spontaneously based on its own and its owner's daily schedule, communicates naturally, provides information, manages daily schedules, looks after the home while the family is away, and reports unusual situations by email. Such products have developed out of research in robotics and in the case of the Roomba only became successful products on the market through realization that product functionality must be driven by customer needs and potential benefit to the customer (Jones, 2006). This finding supports the motivation behind this seminar to combine a new product development process that is user-oriented with prototyping of new, high-technology cognitive products.

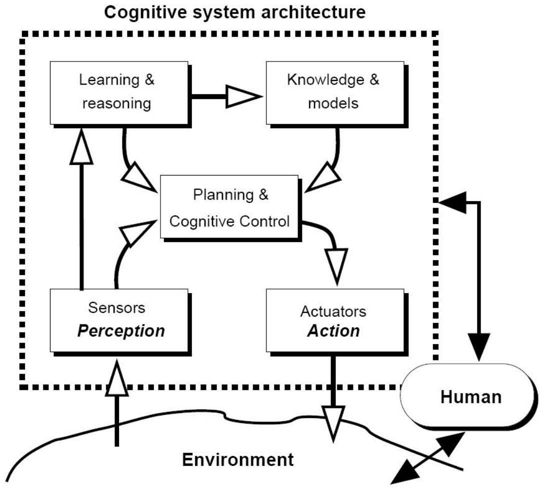

Figure 1. Cognitive system architecture (according to Beetz et al., 2007)

3. Seminar Overview

The seminar mimics several conditions of industrial new product development including innovation as the main driver, working in interdisciplinary teams, working across distributed work sites, strong time and budget constraints as well as giving presentations in English. The seminar is targeted at Masters level students from Mechanical Engineering, Electrical Engineering and Computer Science, who work in teams of three to five people. The seminar lasts one semester, approximately 15 weeks long. A budget is given for prototyping with the possibility to increase it if warranted for special hardware components.

Each semester a new topic area within cognitive consumer products is developed in collaboration with an industrial partner. A workshop prior to the seminar is held with the company to introduce the ideas of cognitive products and identify potential areas where cognitive capabilities could advance their current product range or define new product areas. In contrast to other PBL approaches, industry does not pose a specific design task but rather helps to define more general areas of interest within cognitive products. This provides a boundary for the students' research while leaving enough scope for many product ideas. Each team in the seminar is then tasked to develop a new product opportunity, within the scope given, design a new product and test their concepts through building functional and form prototypes. Since the seminar involves matching cognitive capabilities with emerging trends and user needs, it combines technology-push, in the general area of CTSs and related software and hardware, and market-pull through taking a user-centered approach.

[2] *http://www.mhi.co.jp/kobe/wakamaru/english/*

The seminar is challenging for students since the topic of CTSs and cognitive products is new and most students do not have much experience with prototyping. Further, most students have not been given such an open-ended design task before and have not carried out interdisciplinary projects before, working closely with students from other engineering and scientific areas. While unavoidable due to the focus around cognitive products, it is also commonly thought that technology-push products are more difficult to conceive and develop (Ulrich and Eppinger, 1995). These considerations, among others, were taken into consideration when developing the seminar.

3.1 Process

The process used in the seminar (Figure 2) is adapted from that created by Cagan and Vogel (2002) and used in their iNPD class at Carnegie Mellon (Vogel et al., 1997). This process was chosen since it focuses on the early phases of new product development, i.e. defining new product opportunities, and takes a user-centered approach to develop products that are useable, useful and desirable (Cagan and Vogel, 2002). It is especially important when working on high-technology products to emphasize user aspects so that technology development is directed towards user needs and the potential to enhance user experiences. Due to the high-tech nature of the functional prototypes envisioned, the process was adjusted to give significantly more time for developing the prototypes. As such, the original phase I, “Identifying a product opportunity”, and phase II, “Understanding a product opportunity”, have been combined into a single phase. This has been effective to give students some time to develop their own product opportunities and understand users while providing enough time to follow this through to making working prototypes.
The seminar combines interactive lectures on key topics for the project (Figure 2), workshops providing necessary hands-on skills and team meetings with coaches. The next sub-sections briefly describe each phase and the particular adaptations used in this seminar.

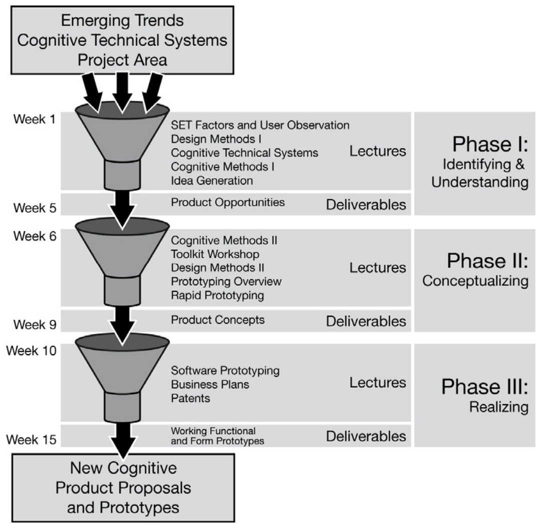

Figure 2. New product development process overview (adapted from Cagan and Vogel, 2001)

Phase 1: Identifying and Understanding Product Opportunities

A product opportunity is a product that fills the gap between what is currently on the market and the possibility for new or significantly improved products that result from emerging trends, (Cagan and Vogel, 2001). In the first phase, students generate several product opportunities that match the potential for cognitive capabilities, e.g. learning user preferences and user behavior, with user needs and desires. Students observe target users and gather research on emerging trends through SET

(Social, Economical and Technical) factors. SET factors drive the need for new products, e.g. the increasing number of single person households (social), the growing interest to save energy costs (economical) and cheaper and smaller electronic components (technical). In addition, a target scenario, i.e. which user and in which situation will use or need the product, is developed along with a rough product requirements list. As part of the students' research, a workshop with the industry partner is held to enable the students to experience and assess the company's current product range as well as discuss early ideas with domain experts. For example, students visited test kitchens so that they could better understand the current process of cooking a meal with the company's highest technology products.

Phase 2: Conceptualizing Product Opportunities

The goal of phase two is to turn a product opportunity into product concepts that are useful, usable, desirable and technically feasible. The tasks include further developing cognitive functionality, generating alternative product concepts, testing product concepts using prototypes and iterating while gaining feedback on prototypes. The phase is completed with the first rough prototypes that show the intended functionality and product form. The lectures of the second phase provide more in-depth information on methods. In particular, an overview of cognitive methods and algorithms, mainly machine learning, is given. This aspect is essential for the students to achieve any level of cognition in their prototypes and is under further development to identify a small set of key methods. An extra workshop is provided for small groups of students where the hardware and software toolkit is introduced and students use it to build several examples.

Phase 3: Realizing Product Opportunities

Phase three focuses on testing the chosen product concept through more in-depth prototyping. The goal is to develop a functional prototype that clearly demonstrates at least one of the envisioned cognitive capabilities of the product opportunity. Additionally, the students are encouraged to think about potential commercialization including issues such as cost, market competition, business plans, intellectual property and patents. At the end of this phase a final presentation on the product proposed is given including a demonstration of their functional as well as form prototype.

3.2 Soft Skills

The seminar also provides students with the opportunity to improve their soft skills, which is becoming increasingly important for young engineers. Students are required to present to an academics and industrial audience three times during the semester, gaining feedback on their presentation skills. Since nearly all the students are native German speakers, the seminar also provides the chance to present in English, as they might be asked to do in an international company. This is a unique opportunity for them. Further, the ability to integrate quickly in a new team, typically with students that they did not know previously and to work with students from different educational backgrounds is gained. Finally, in rotation, a team leader for each phase is chosen by the team so that multiple students gain experience running meetings and understanding the challenges of effective team leadership to meet the deliverables.

3.3 Seminar Infrastructure

A hardware and software toolkit has been developed for the seminar to introduce the students to prototyping CTSs and give them a starting point. Due to the high variation of student backgrounds and skills across departments, it is necessary to provide toolkits that can be learned quickly by all as well as flexibly adapted and extended to a wide range of prototype needs. To enable straight forward integration of different sensors and actuators, the hardware toolkit is based around Phidgets[3]. It provides an easy to use interface between the software infrastructure and the hardware. Two software

[3] *www.phidgets.com*

infrastructures are provided, Player/Stage[4], a sensor control interface and simulator commonly used in robotics research, and Labview, a sensor control interface based on graphical programming. The students are taught to use the toolkit, but are not forced to use it. Since realizing products with learning capabilities and interaction with users are common aspects of projects, multiple libraries for machine learning are provided along with software interface development guidance. Finally, a range of workshops are provided to assist in making form prototypes including use of different rapid prototyping machines (FDM, 3D Printer) and model making tools such as 2D laser cutting and 3D foam milling.
To reach the seminar goals in the given timeframe, teams are supported by scientific assistants (PhD students) from the three departments involved and the UnternehmerTUM who serve as team coaches. Each team has one fixed process coach who is responsible for guiding the team through the new product development process and give general support. In meetings at least once a week, the progress of the teams and their plans are reviewed as well as technical issues discussed. Further, coaches in a range of technical areas, including hardware, software, design methods (Lindemann 2007), CTSs, and entrepreneurial issues are provided.
Finally, to aid collaboration, a groupware system was installed, so that the teams can store their work and project information digitally, in one place. This was installed especially to support distributed collaboration since the Electrical Engineering department is located 20km from the Mechanical Engineering and Computer Science departments.

4. Results

The first seminar during the summer semester 2007 (April-July) was run in collaboration with the energy company E.ON on the topic of cognitive products to promote energy savings in the household. Ten students (nine mechanical engineers and one electrical engineer) in three teams attended the seminar. Two teams focused their product proposals around the general idea of cognitive power strips and sockets that respond to user behavior and save energy wasted by electronic devices in standby mode (Figure 3). The third team focused on one typical electric energy consumer in the household, the refrigerator, developing a cognitive add-on product to reduce wasted energy from opening and closing the refrigerator throughout the day. This team is attempting to patent their product and established a startup company to develop it receiving seed funding from the German government.

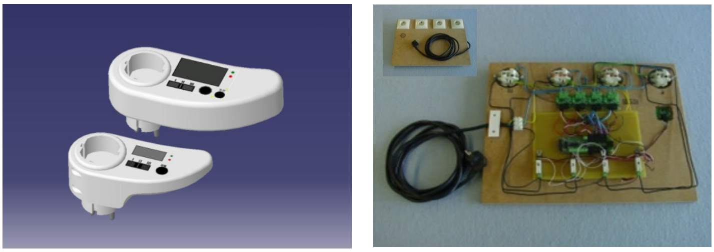

Figure 3. Form prototype of integrated cognitive sockets (left) and functional prototype of cognitive power strip (right)

The first team focused on a power strip that switches off if plugged in devices are on standby and assumed no longer used according to a learned daily schedule. This was achieved using a current sensor and an override button (Figure 3 right). The second team developed a more sophisticated product (Figure 3 left): a number of sockets with different sensors (sound, light, movement, current) are distributed in the room. All “slave” sockets gather data and send it to “the brain”, which decides if a socket can be turned off based on the input data and learning if someone is in the room and will need a device. The third team used, in addition to the current sensor, a temperature sensor within the

[4] *http://playerstage.sourceforge.net*

refrigerator. According to measured temperature and user behavior, opening and closing of the door, the device disconnects the refrigerator from the power supply system to save energy. The product is an add-on to existing refrigerators and can be used with both old and modern refrigerators, with the greatest energy savings benefit being for old refrigerators.

All teams used a decision-tree algorithm on a current/time dataset clustered with k-means to realize the adaptation of their product to user behavior. The team with the integrated sockets also used neural network that was trained to make decisions based on the different sensor inputs as to who is in which room and to react accordingly. Key summary findings of the seminar are that people want to save energy but do not want to change their behavior. Collectively, the teams found that there is a new opportunity to develop cognitive products that work in the background, adjust to a learned daily schedule, turn off devices when not likely to be used and give feedback to users.

The second seminar in the winter semester 2007/2008 (October-February) was held in collaboration with Bosch and Siemens Home Appliances (B/S/H) on the topic of cognitive cooking devices for the intelligent kitchen. Three teams of 5 students (twelve mechanical engineers, one computer scientist and two electrical engineers) took part in the seminar. Key areas included user and food recognition, products that adapt to user behavior and preferences as well as improve with experience. One project developed an oven that automatically adapts cooking programs based on user feedback, via a wireless interface, and the measured food temperature profile. Another team developed new software to help people loose weight, through adaptive recommendation of food points to consume based on user input of daily eating, exercise, weight and desired weight loss.

5. Discussion

In designing and running the seminar for two semesters experience has been gained and lessons learned by the core team involved. Key strengths from the students' perspective include the focused, interactive lectures by experts that provide deep insight into all relevant fields needed for the project, the topics of which are generally beyond their normal lectures. The entrepreneurial approach was successful as students reported being motivated by the great latitude given to them to define their product opportunity and if successful work towards putting a new product on the market. The high level of interactivity with students, coaches and professors was also highly appreciated by the students. While the number of students participating from electrical engineering and computer science has been low to date, the interdisciplinarity of the topic was valued by students as a chance to tackle design tasks in a different domain, which is uncommon in their studies. This serves as one way to start breaking down students perceptions about domain boundaries. In the end, all students praised the open and informal style of the seminar which ensured a good collaborative atmosphere during the semester in combination with the strong process and technical support from the coaches.

Critical comments from the students in the first semester and reflection on the seminar have already resulted in modifications in the second semester including fewer presentations, further concrete examples of cognitive products early in the seminar and more time for prototyping. These changes improved the results of the seminar significantly. In addition, the difficulty of coaching students to form effective teams was underestimated initially and so all coaches have been professionally trained on coaching skills. It is continuously difficult to find the right balance between supplying students with enough basic theory and concepts to think about new cognitive products, but also guiding them to completion of a functional prototype within the tight schedule. It was found that it is critical that the students understand the idea of cognitive products very early on in the seminar as well as giving strong examples of how cognitive products can be realized with both hardware and software methods. Lectures are being further extended and adapted with more practical examples so that students are able to both understand the new concepts and quickly see how to put their new knowledge into practice within the context of their product ideas. Through experience in teaching this seminar, it is hoped that we can improve the process and infrastructure to develop an effective means for teaching new product development in high-tech areas such as cognitive products.

6. Conclusions

This paper reports the successful establishment of a new type of interdisciplinary, project-based seminar at TUM, where students create new cognitive consumer products. Due to the high technology nature of cognitive products, the focus is more technical than typically found in new product development projects and is achieved by the integration of electrical and mechanical engineers together with computer scientists as well as project-oriented, technical lectures and a software and hardware prototyping toolkit. The seminar balances the open-ended nature of new product development with user-centered design and hands-on prototyping to both find new product opportunities and see them through to a working functional prototype and form prototype. This balance is difficult to achieve and undergoes continuous adjustment. The seminar has been successful in meeting the goals defined, the main being educational, and providing students with interdisciplinary, hands-on experience and exposure to the cutting-edge research topic of cognitive technical systems.

Acknowledgements

Innovation@CoTeSys is part of the research cluster of excellence, Cognitive Technical Systems (CoTeSys), funded by the Deutsche Forschungsgemeinschaft (DFG) within the "excellence initiative" from 2006-2011. The authors would like to thank many people who have contributed to the creation and running of this seminar including Prof. Michael Beetz, Prof. Klaus Diepold, Prof. Lindemann, Prof. Tim Lueth, Prof. Frank Schiller, Dr. Helmut Schönenberger, Walter Bamberger, Ferdinand Heindlmeier, Bernhard Kausler, Alexis Maldonado, Mathias Markert, Thomas Meiwald, Federico Ruiz and Dr. Stefan Weber.

References

Beetz, M., Buss, M. and Wollherr D., "Cognitive Technical Systems — What Is the Role of Artificial Intelligence?", Proceedings of KI 2007: Advances in Artificial Intelligence, 2007, pp. 19-42.

Brachman, R.J., "Systems that know what they're doing", Intelligent Systems, Vol.17, No.6, 2002, pp. 67-71.

Cagan, J. and Vogel, C. M., "Creating Breakthrough Products: Innovation from Product Planning to Program Approval", Upper Saddle River, NJ, Financial Times Prentice Hall, 2002.

Dodds, Z., Greenwald, L., Howard, A., Tejada, S., and Weinberg, J., "Components, Curriculum, and Community: Robots and Robotics in Undergraduate AI Education", AI Magazine, Vol. 27, No. 1, Spring 2006, pp. 11-22.

Dym, C.L., Agogino, A. M., Ozgur, E., Frey, D.D., Leiffer, L.J., "Engineering Design Thinking, Teaching, and Learning", Journal of Engineering Education, January, 2005, pp. 103-120.

Jones, J. L., "Robots at the Tipping Point: The Road to the iRobot Roomba", IEEE Robotics & Automation Magazine, March, 2006, pp 1-3.

Lindemann, U., "Methodische Entwicklung technischer Produkte", Springer-Verlag Berlin Heidelberg, 2007

Paetzold,K., "Integration of Learning Aptitude into Technical Systems", Proceedings of the 17th CIRP Design Conference - The Future of Product Development, Springer, 2007, pp. 639-648.

Ulrich, K.T. and Eppinger, S.D., "Product Design and Development", McGraw-Hill, 1995.

Vogel, C. M., Cagan, J. and Mather, J. H., "Teaching Integrated Product Development: Educational Innovation at Carnegie Mellon University", Design Management Journal, Vol. 8, No. 4, 1997, pp. 58-65.

Prof. Dr. Kristina Shea
Virtual Product Development, Product Development, Technische Universität München (TUM)
Boltzmannstr. 15, 85748 Garching, Germany
Tel.: 089/289 15143
Fax.: 089/289 15144
Email: kristina.shea@pe.mw.tum.de
URL: http://www.pe.mw.tum.de