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Integrating the development of continuous improvement and innovation capabilities into engineering education

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In this paper, a study is presented in which engineering students at a Danish university developed Continuous Improvement (CI) and innovation capabilities through action research and experiential learning methods. The paper begins with a brief overview of the literature on CI and innovation, followed by an account of how the students designed and implemented solutions to self-identified problems within their educational program using the principles of CI, and how these learning activities facilitated the development of basic innovation capabilities. The paper concludes with insights regarding how such an innovative design of teaching methods based on learning-by-doing may not only support the development of CI and innovation in engineering students, which is increasingly demanded by industry, but also represent a way in which to enhance sustainability and innovation of the education itself.

Keywords: Continuous improvement and innovation in engineering education; Action research; Case study

1. Introduction

The proliferation of courses on innovation offered at universities and in particular in engineering programs evidences an ever-increasing awareness of the need to equip the coming generation of engineers with knowledge about innovation. Still, teaching about innovation is clearly not the same as supporting the students' development of the capacity to be innovative. From studies on the development of innovative capability in organizational contexts, it has become clear that innovative capability requires practice and experience with particular tools and methods and that innovative capability is fostered in environments that support employees in solving problems and developing innovations involving their own work processes (Hesselbein *et al.* 2002). Often this developmental process begins in organizations by first introducing Continuous Improvement (CI) and then using learned tools and methods in projects targeted at sustained and continuous innovation of products, services, or processes.

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Increased innovation in engineering education can be approached from two directions: efforts can be targeted to more innovative teaching practices and courses on innovation can be incorporated into the existing curriculum. In the case of the former, the focus is primarily on ways of creating new methods of developing the students' technical (i.e. engineering) knowledge. Problem-based learning (PBL) and project-oriented group work such as that used at, for example, Maastricht University, The Norwegian Technical University, and Aalborg University are pedagogical approaches to teaching that provide students with the opportunity to analyze and provide solutions for problems relevant to their subject area and various relevant parameters (e.g. economy, available technology, sustainability; Kolmos 2006). PBL and project-oriented group work is in itself considered an innovative teaching design that differs dramatically from traditional (i.e. lecture) university teaching. Further, these approaches to teaching appear to foster innovative thinking in the students as they seek to develop creative and novel solutions (von Krogh *et al.* 2000).

The study presented in this paper presents a model for incorporating both of these approaches to innovation in education, namely teaching students about improvement and innovation through the use of innovative teaching methods and practices, in order to provide students with the opportunity to develop innovation capability. In the next section of the paper, a brief introduction to CI, innovation, and continuous innovation is provided. Thereafter, the study is described and discussed in terms of the students' innovation knowledge and skill development.

2. Continuous Improvement, innovation and continuous innovation

Continuous Improvement has been defined as "the planned, organized, and systematic process of ongoing, incremental and company-wide change of existing practices aimed at improving company performance" (Boer *et al.* 2000, p. xxiii). Continuous Improvement (CI) has all but become commonplace in the manufacturing companies during the past few decades (Schroeder and Robinson 1991). While generally considered a bottom-up change strategy that emphasizes shop-floor level involvement and participation, CI is becoming more common in other areas of the organization, for example in new product development departments and supply chain networks. The implementation of CI in service organizations, such as hospitals and governmental agencies (Berwick 1989) is also becoming more widespread.

Recently, and particularly in elementary education in the USA, CI has been extended to educational institutions in an effort to improve the administrative and teaching practices, and consequently, the students' learning processes (Kendell and Taylor 2003). In many cases, implementing CI in a school signals a dedication to quality of the education (Hawley and Rollie 2002). Thus it appears that educational institutions are becoming aware of the potential value of using (at least some) CI principles to improve their "business processes". It is, however, worth noting that the improvements described in these cases appear to be planned and implemented primarily by the administrators and possibly the teachers. As long as the improvement initiatives are targeted towards improvement of administrative practices alone, this does not appear to be in conflict with CI, which is strongly grounded on active participation of those most directly involved in the processes to be changed. On the other hand, it is questionable whether improvements concerning the teaching and learning processes that do not involve the students themselves—who in this case can be likened to the shop-floor workers in a traditional manufacturing company—could also be classified at CI. Further, while the students may certainly benefit from the results of CI initiatives, their lack of involvement in identifying and solving problems does not provide them with the opportunity to learn CI skills or capabilities.

While CI is focused on improving existing practices, the objective of innovation is the (re)creation of new products, processes, positioning (of the company or the products), and/or paradigms (Francis and Bessant 2005). Innovations are traditionally considered more finite entities with a relatively clear demarcation between the generation of a new idea and the generation of the new product, service or practice based on that idea. CI is viewed more as a flowing process of continuously and consistently improving and it is not always obvious where one improvement starts and another stops, as the emphasis is on building steadily on each solution. With innovation, members of organizations are encouraged to think outside of the box—or perhaps to even forget that the box exists; CI is more about fixing what is already in the box.

Continuous innovation, which may also be referred to in the literature as "CI", falls comfortably in between the definitions of Continuous Improvement and innovation, being described as "an organisation-wide process of focused and sustained incremental innovation" (Bessant and Caffyn 1997, p. 8). In other words, there should be a continuous process of developing new ideas that are based on previously developed new ideas. Once again, as with CI, continuous innovation stresses the importance of organization-wide involvement, a feature not usually emphasized with innovation.

The terms Continuous Improvement capability and continuous innovation capability are both used in the literature, again often interchangeably. Caffyn (1999) defines CI capability as "the ability of an organization to gain strategic advantage by extending involvement in innovation to a significant proportion of its members" (p. 1142) and continuous innovation capability is defined as an "organization's capacity to gain advantage by implementing more and better ideas than rivals" (Francis and Bessant 2005, p. 171). Bessant and Caffyn (1997) suggest that the development of CI/continuous innovation capability occurs as core abilities or behaviors are learned and practised routinely within the organization. At the starting point, these core abilities and behaviors involve the use of various problem-analysis and problem-solving tools, for example the Plan–Do–Check–Act (PDCA) wheel, cause and effect diagrams, fishbone analyses, and brainstorming of potential solutions to identified problems. (Continuous) Innovation involves use of such tools and methods creatively and insightfully in order to develop new solutions quickly, on the basis of a solid knowledge base, or as Prusak (1996) states: "the only thing that gives an organisation a competitive edge, the only thing that is sustainable, is what it knows, how it uses what it knows, and how fast it can know something new" (p. 6).

Although it appears that Continuous Improvement and innovation capabilities are becoming increasingly important for the sustainability of organizations (Tidd *et al.* 1997; Marti 2000), there is little documentation to support that educational institutions have made concrete efforts towards integrating the development of these capabilities into the design of their existing curricula.

3. Research objectives

The initial objective of the study presented in this paper was to use the principles of CI to improve issues the students themselves identified as problematic in their study program while supporting the students development of develop basic CI capabilities, which were deemed relevant to their specific educational program. Because the students participating in the study were enrolled in an engineering program that includes a number of courses on CI and innovation, it was considered an ideal setting for using action and experiential learning methods to facilitate the students' development of CI skills.

Once the students became involved in the CI activities, patterns of thinking and idea generation began to resemble those generally associated with continuous innovation, rather than (just?) CI. This rather serendipitous discovery provided a host of speculations on part of the authors, especially with respect to ways in which innovation capability could be learned through action/experiential learning. The paper therefore also includes an analysis of the process by which the students appeared to move from practising CI to innovation and herein began developing CI and innovation capability through participation in the study.

4. Background, setting, and methods

The project described in this paper takes place in what is referred to at the Basis Year program (i.e. freshman year) of the Global Business Development (GBD) program, which is one of the 16 main educational programs offered within the Faculty of Engineering and Science at Aalborg University. In total, about 700 students are enrolled in the Basis Year program. First, the structure of the program is described to provide a background for the case, and then the methods that were used to implement CI together with the students from the GBD program.

Aalborg University follows a problem-based project-oriented model of structuring its curricula. All programs at the university begin with the Basis Year program, which includes courses applicable to all students as well as courses specific to the particular education (e.g. GBD). The GBD program was launched in 2003 within the Faculty of Engineering and Science at Aalborg University for students seeking either a three-year bachelor's degree or a five-year master's degree. At the time of the study, there were 91 students enrolled in the program: 42 in the first year; 35 in the second year, and the 14 third-year students comprising the first GBD class. The Center for Industrial Production (CIP) is responsible for the general administration and development of GBD as well as a majority of the teaching and advising of the students enrolled in the program.

The overall aim of the Basis Year is to introduce students to work in a scientific way with emphasis on methods, theories and models (Aalborg University Study Guide 2005). Another aim is to qualify students for continued studies within the Faculty of Engineering and Science and to train the students in claiming responsibility for their own learning. Each of these aims is addressed through a combination of problem-based project-oriented group work and the coursework. The students work in project groups with 5–7 members. Each group chooses a project that conforms to the theme of their specific educational program. A main advisor is allocated to each group in order to facilitate the project work, and there is also a coordinator for each semester that ensures the overall functioning of the students, coordination of their studies with the educational program as a whole, and the continuous development of the program. The advisors and the coordinators are selected by the developers of the individual programs (e.g. GBD).

One way in which the coordinator supports the students is through steering committee meetings that are generally held once a month throughout the year. One student from each project group is elected by his or her fellow students to serve as student representative in the steering committee meetings, and thus update the coordinator of any problems or issues that need to be addressed regarding the courses, teachers, projects, advisors and physical conditions of the study environment. A summary of the meeting notes is written in collaboration between the student representatives and the coordinator and then provided electronically to all members of the study board, the students, teachers and advisors within the given program. In this way, all parties involved in the program, as well as in its administration and development, are provided with regular feedback on how well the program is functioning. When relevant, issues

taken from the steering committee summaries may be discussed at the monthly coordinator meetings. The steering committee summaries also provide a means of communicating general information (e.g. course changes, upcoming events) to the students.

The first author of this paper served as action researcher in this project, through her capacity as semester coordinator of the Basis Year program for the Global Business Development educational program. The study began in the fall 2005 when a research plan was provided to the study board director and CIP. The research plan involved using principles of CI to improve the quality of the GBD program. According to the research plan, the students themselves, in collaboration with the semester coordinator, would be actively involved in analyzing problems and implementing potential solutions, as well as monitoring improvement initiatives and evaluating their effectiveness. Upon approval of the plan by both parties, the steering committee, consisting of one student from each of the six project groups enrolled in the program, was convened in order to present the research plan and to determine whether the students were interested in participating in further study. As all of the steering committee members were enthusiastic about participating in the study, plans were made to run October to December 2005, with additional follow ups for data collection during the spring (2006) semester.

5. Using CI methods

The six student representatives and the semester coordinator that comprise the steering committee held an introductory meeting where the plans for the study were discussed. Specifically, the students were informed that they would be attempting to identify problems or issues within the educational program or conditions that might influence the quality of program, with the help of their respective groups. The progress of the steering committee as it relates to the study is depicted in table 1.

Table 1. CI implementation schedule.

Activity	CI methods used
Meeting 1: Presentation of study proposal	Introduction to PDCA model
Follow up in own groups: identification of potential areas for improvement with other students in respective groups (no facilitator)	Brainstorming, prioritizing, decision-making, group communication
Meeting 2: Identification of 2 projects considered relevant and potentially changeable	Problem-analysis (e.g. fish-bone and cause and effect diagrams), prioritizing, scenario testing
Meeting 3: Generation of solutions and creating action plans	Activity diagrams of potential solutions, project management skills (timelines, identification of necessary resources)
Follow up: Development and implementation of solutions	Negotiating, contracting and collaborating with external contacts (i.e. "cross-functional cooperation"), planning, delegation and scheduling
Meeting 4: Evaluation of implemented solutions; planning of modifications	Collecting and evaluating feedback, brainstorming, problem-analysis, planning
Follow up: Development and implementation of modified solutions	Cross-functional scheduling and planning
Meeting 5: Evaluation of results	Implementation of feedback channels, delegation
Meeting 6: Reflection and generalization	PDCA and Kolb's learning cycle to make learning explicit and to relate to other contexts

6. Identification of improvement projects

The steering committee identified two broad areas in which to focus on improvements during the studies: communication and projects. Two aspects of communication were considered important to improve: providing the students with information about the GBD program in general (e.g. structure, types of courses and projects, future job opportunities) and how the specific courses and projects were functioning. In the case of the first issue, one of the students explained that because the GBD program is so new, there is not a lot of information available about what it really means to obtain an education in the field.

The second issue regarding communication involved how information is relayed between the students and the teachers, as well as to the persons responsible for ensuring the quality of the courses. As mentioned above, steering committee meetings are held regularly as a way of gaining and providing feedback from and to the students about courses, teachers, projects and advisors. These summaries are, however, censored due to the fact that they are published online via an internal network and must therefore not contain any derogatory comments about any named individuals. For instance, specific complaints about particular teachers must not be included in the steering committee summaries. Although the students seem to understand the legal justifications for censoring the meeting summaries, they feel that the censorship eliminates their only real means of communicating problems with the teachers and their teaching.

The second broad area for improvement identified by the students involves the group projects conducted each semester. Since the program's start, all GBD projects have been conducted in cooperation with local industry to allow the students to experience actual organizational issues in their proper context. While having the opportunity to conduct a project in an actual company is quite appealing to the Basis Year students, it also presents some difficulties. Specifically, the students often experience conflicts between the companies' objectives for participating in the projects (i.e. wishing to have an actual problem solved) and the learning objectives established by the university. As Basis Year students have little to offer in terms of knowledge and experience in solving real-life problems in organizations, the companies may also be reluctant to expend the resources which the students need in order to fulfil the project requirements, thus it not uncommon for an organization to back out of a project midstream.

7. Implementing problem-solving

Essentially, implementing the first solution (i.e. providing students with information about GBD) involved the planning of an informational seminar for the students. The seminar was conducted in late winter by one of the directors of CIP (who also leads the development of the GBD program), and it included an overview of the courses and projects in which the students would be participating during the subsequent years at the university, as well as a summary of the types of positions for which the students might apply upon graduation. The students were free to ask questions and meet some of the upperclassmen enrolled in the program and other teachers, advisors, and researchers at CIP. Approximately 82% of the Basis Year students attended the seminar.

The students wished to conduct unofficial steering committee meetings as an extension of the regularly scheduled meetings to allow the opportunity to discuss problem issues that were deemed too sensitive for publication on the internal network (i.e. via traditional steering committee meetings). It was agreed that when such issues arose, the semester coordinator would be notified that an extended meeting would be necessary. Notes were taken separately for each segment of the meeting: the first set of notes would then be used as the official summary

of the meeting and the second would remain confidential. It was then the responsibility of the semester coordinator to make arrangements for addressing the issue at hand. In one case, these arrangements involved contacting the teacher responsible for a particular course to make minor changes in the teaching format. The steering committee members were apprised of any actions being taken, and emails were sent to the individual groups to update them on the status of the problem.

The students' suggestion for improvement of the projects at the Basis Year involved reducing or eliminating the projects' dependence on working with a specific company, but they were not sure how best to accomplish this while still providing students with the opportunity for some contact with "live" organizations. Therefore, a meeting was called between the GBD developers and some of the project advisors to design a plan. In this meeting, it was decided to replace the work in companies with a written or video-recorded case that encompasses all of the learning objectives for the students, and to schedule site visits to a company with similar characteristics as the case company. During the winter break, an interactive multi-media case was purchased on which the students based their projects. The students have also completed a tour of a company with similar operations as those depicted in the case and are scheduled for a second tour in another company later in the spring.

8. Evaluation and modification of improvements

An important but often overlooked phase of CI implementation is the evaluation—and possible modification—phase, when the results of implemented solutions are scrutinized to ensure that the initial goals have been met satisfactorily. The students participating in the study were therefore facilitated through this evaluation and modification process. The students conducted informal review sessions within their own groups, soliciting feedback from each of the group members, and then summarized these for the steering committee. In the following, this feedback is summarized, along with a description of the modifications to be made to the plans.

The students who had attended the seminar to gain information about the GBD program were overwhelmingly satisfied with the experience. Many students wrote emails and provided oral feedback describing how they had benefited from receiving information about the program. Several students stated that they felt a renewed interest and enthusiasm for the program after having attended the seminar. The only complaint registered about the seminar was that it was held too late in the semester. Therefore, plans were made to modify the improvement initiative by conducting the seminar shortly after the start of the first semester of the Basis Year. Some of the written materials provided to the students at the seminar were also added to a student website that could be visited by current and future students. Subsequent follow up on these modifications indicates that the students are satisfied with the channels of communication about the GBD program that are now available to them.

The unofficial steering committee summaries that dealt with sensitive issues that would be censored from regular meeting summaries appeared to be partially successful in providing the students with the ability to positively influence the teaching. In the one instance mentioned above, the structure of the teaching was improved after feedback was received from the students. However, this solution also appears limited in several ways if it is going to be used in other contexts. First, the unofficial steering committee notes that are sent to the students only do not provide the documentation that might be needed if the problem cannot be easily resolved. In other words, there is no way to document repeated problems that might be used in a performance review.

Secondly, the solution implemented here, which involved speaking directly to the person responsible for the course, was enabled by the fact that the semester coordinator had a working relationship with the teacher in question. Even so, the communication between the students and the coordinator and on to the responsible party and then back to the students required a considerable amount of time, especially given that the course instructor wished to speak with the students directly, before taking any action. Had s/he been employed in another department, communication might have been even more difficult and may not have resulted in any actions being taken, as cooperation between departments is often limited. The only way to ensure that action is taken would be to bring the problem to the attention of the study board, which would happen naturally if this information were allowed in the official steering committee meetings. Therefore, the students agreed that rather than simply sending the unofficial steering committee summary to the students, it would also be made available to the study board through confidential channels. This modification was tested in the subsequent semester and appeared satisfactory, although it should be noted that there were no sensitive issues to be managed during this time.

The implemented solution to the second problem addressed involved using a multi-media case as the basis of the students' projects so there was less reliance on industrial cooperation. The solution proved to be highly successful and evaluation of the students' projects at examination revealed that projects conducted in this manner were more aligned with the learning objectives established by the university. Therefore the students did not feel a need to implement modifications to the solution.

9. From continuous improvement to innovation

After the students reconvened in January 2006 and the first steering committee was held for the spring semester, the students asked to continue with the study for the remainder of the year. They felt that by continuing the study, they would be able to influence their program positively and believed they were learning important new skills through their participation in the study. The students were encouraged to return to their project groups and conduct a brainstorming session to identify additional issues they would like to use as the basis of the subsequent CI projects. This time, the students presented problems with obtaining support for some of their classes because of large class sizes and feeling too detached from the main GBD study program. As previously mentioned, the Basis Year is relatively isolated both geographically and organizationally from the second, third, and fourth years of study.

Following essentially the same process as before, the students began to develop solutions to these problems. However, they often became frustrated by perceived constraints (e.g. organizational and financial issues) and the semester coordinator (first author) suggested they try to "think outside of the box" when trying to identify solutions. At this time, the students were introduced to a model of the innovation process developed by Tidd *et al.* (1997) that depicts innovation as developmental process with four stages: signal processing, or environmental scanning, strategy development and action planning, resourcing, and implementation. A feedback loop is built into the model that includes reflection, learning, and re-innovation.

One example of an "innovation" developed by the students involved the development of a plan for restructuring two of their classes into workshops that would allow them to receive the support they felt was needed to successfully complete some of their class exercises. In this design, rather than the teacher conducting traditional lectures for two hours and then sending the students to their group rooms to work, the classes are taught in 3.5-hour blocks with the teacher and an aid moving regularly between lectures and in-class exercises. The auditorium

that had been used for teaching previously proved problematic for this design, so the students submitted a request to the study board to reorganize two lounge rooms that would provide ample space for working on the exercises during class time. Each of the stages of the innovation model (Tidd *et al.* 1997) was completed as follows.

- *Signal processing*: the students researched innovative teaching forms at other educational institutions for inspiration and combined this information with a careful scrutiny of the teaching model used at Aalborg University.
- *Strategy*: the students developed action plans based on the structure and organization of the Basis Year program, linking their plans with the learning objectives established by the study board and sought advice from members faculty and staff.
- *Resourcing*: the students negotiated and contracted with the faculty and study board in order to gain approval of their plan and to ensure implementation.
- *Implementation*: the new teaching form was piloted with two of the students' courses in the spring 2006 semester.
- *Learning and re-innovation*: the students developed and conducted an evaluation of the new teaching form and received feedback from the students and faculty. Based on the results of the evaluation, the teaching form has been modified to incorporate more of the theoretical work traditionally delivered by lectures into the group activities. This has further shortened the length of the lectures.

The students also developed ideas for increasing contact between the first-year students and the students from upper levels of the GBD program, including regularly scheduled visits to company seminars and workshops and social activities. Further, the students in the steering committee arranged for senior students to serve as project mentors during their projects and together, the students have created a student network that allows for file sharing, planning activities, and "chatting".

10. Results

Although no system was established for collective objective data to support the students' development of CI and Innovation capabilities, students' own accounts of this development should not be dismissed. For instance, one student stated the following:

> It used to be when there was a problem we'd just get angry about it and complain to each other or maybe the person responsible. Then we learned how to really look at the problems from a new angle and we realized how easy it is to make a wrong assumption about cause and effect. That by itself was a big thing. But now it feels like we have so much more power because we don't let limitations and constraints get in our way. We know that if we hit a brick wall, we probably need to put on a new set of glasses or climb a hill or something else to be able to see the wall from a new angle. Or maybe we need to look in a totally new direction. We've become more creative and more positive in this process, that's for sure (quote from 2nd semester engineering student, March 2006).

In addition, review of the process analyses the groups write at the completion of each project indicate that capability development has occurred for these students. Specifically, the process reports suggest that groups which were involved in the steering committee project were much more likely to make frequent use of time and project management tools and methods, take part in brainstorming and group decision-making, and collaborate with external contacts when completing their projects.

Four of the six student participants also developed projects involving CI and/or innovation for the subsequent semester. Although the latter could simply be due to their being introduced to the concepts, it also indicates an interest on the part of the students that had not been

expressed in previous semesters or by the non-participating students. Finally, the six students who participated in the study have developed a plan to continue working together as groups to discover ways to support the further improvement and development of their educational program once they leave basis and begin their third semester at the university.

11. Conclusion

The purpose of this paper was to present a pilot project that was characterized by an innovative teaching form that focused on using experiential learning methods to support the development of CI and innovation capabilities in freshmen engineering students. This teaching form is construed as being innovative by going far beyond the PBL and project group structure already practised at Aalborg University, which in itself is considered an innovative design. The students demonstrated that learning by doing provided them with opportunities to experiment with CI and innovation with issues they personally deemed relevant and important, much as would be expected once they graduate and begin their professional careers. For this reason, these engineering students may be getting a head start on the development of the capabilities organizations are beginning to site as critical for sustainability in the near future. At present, plans are being made to continue the study throughout the participating students' academic career and then once they secure employment, in order to determine the degree to which the capability development influences their future positions and the organizations in which they work. The findings of the proposed extension of this study should help address questions related to the sustainability of the teaching design as well as the sustainability of the developed capabilities in other contexts.

As this is a very small study, involving only one group of students enrolled in one of many educational programs at the university, it is impossible to draw conclusions that would be applicable in other educational settings. On the other hand, the cases are presented here in sufficient detail that it should be possible for the studies to be replicated and compared to the literature on CI and innovation, in an effort to further develop knowledge and theory concerning CI and innovation capability development.

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