Sustaining Student Competitions through Senior Capstone and Knowledge Management Systems

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Abstract

Capstone design courses and student chapter design competitions offer students a variety of opportunities to gain project engineering and management experience. Commonly, student design competitions are supported through associated senior capstone design projects, providing the chapter with the resources necessary to produce a quality product. Within the organization, the capstone design students and student chapter members must be able to coordinate efforts to produce, manage, and transfer knowledge from year to year. Through senior matriculation and transient membership, high turnover rates result in the loss of organizational knowledge for future members. In this paper, the authors present a conceptual model for the creation of an organizational structure that involves active knowledge management through accessible processes and defined responsibilities. By analyzing different management structures, a system will be proposed that addresses the importance of maintaining knowledge and information through the student organization instead of individual members. The proposed knowledge management system will encourage regular use by all members, and provide a framework for future project management.

Keywords
Knowledge Management, Student Organizations, Capstone
1. Introduction

In order to graduate from an ABET accredited engineering program students must complete a technical project. This project is often referred to as senior project or capstone project. Through this project students must show that they are able to design “a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability” [1]. There are many student competitions that meet these requirements. In the school of Mechanical Manufacturing and Industrial Engineering (MIME) at Oregon State University (OSU) two specific examples of these types of projects are the Design/Build/Fly (DBF) competition and the Experimental Sounding Rocket Association (ESRA) Intercollegiate Rocket Engineering Competition (IREC). The Society of Automotive Engineers (SAE) also offers many student competitions that can be used as senior projects. This paper will explore various knowledge management systems that can support a partnership between senior capstone design and student design competitions.

The SAE projects at Oregon State have been mainly designed and manufactured by capstone students over the past ten years and have achieved great success. OSU competes in both the Baja and Formula competitions, both of which are large-scale projects, which require designing and building a full-scale vehicle that fits a driver. Teams often use the design from previous years and consider ways to improve the product. Each project requires many capstone students who are all assigned to a specific part of either SAE project. This program has won many championships and has provided a model so that other student competitions can be used as capstone projects as well.

DBF and ESRA competitions are annual competitions similar to SAE competitions, but the projects are on a smaller scale. These projects are much smaller, and often give students shorter time periods to complete the projects, so the structure from OSU’s SAE program is not directly relatable. The DBF competition challenges students to design an RC aircraft that can complete a certain mission profile, usually consisting of three different flights. This mission profile is changed every year, but often has similar aspects to previous years. Figure 1 shows the 2013 DBF team at the competition in Tucson, Arizona. The ESRA competition challenges students to design and build a rocket that can carry a 10-pound payload and reach an altitude as close to 10,000 feet as possible.

The biggest challenge with competing in these events and using them as capstone projects is that knowledge is often lost from year to year due to the high turnover rate of students. Students usually graduate immediately after completing their senior project, often taking all of the knowledge that they have gained with them. In order to address this issue, the creation and management of knowledge is a crucial element of the organizational operation. This management system must allow information to be stored in a way that allows the team to maintain knowledge and add to it each year. This system must be an active system that allows knowledge to be collected as it is created, capturing knowledge as it is created. By being active, the system will integrate data collection into the team’s everyday workflow. The system will require a team leader who understands the knowledge management system and keeps information up to date. This leader will be responsible for enabling opportunities for students to create knowledge through meetings, work sessions, and other methods discussed in this paper.

2. Literature Review

The below review of literature explores first the nature of organizational knowledge creation, reviews techniques for knowledge creation, and defines the role of the leaders in a knowledge creating organization.

2.1 The Nature of Knowledge Creation
As explained in [2], the process through which an organization creates knowledge follows a cycle of four modes, converting knowledge between tacit and explicit forms within the organization and individual members. In this model of organizational knowledge, explicit knowledge is defined as knowledge that can be recorded as data, figures, or transmitted through clear explanation. Tacit knowledge represents knowledge gained through experience or practice. Tacit knowledge can take the form of intuitions, mental models, or technical skills, and is difficult to share directly with another individual. Nonaka explains that through the processes of socialization, externalization, combination, and internalization, an organization can convert, share, and use the tacit knowledge of individual members as explicit knowledge gained by the organization as a whole.

The method of socialization converts individual tacit knowledge to group tacit knowledge, and can involve socialization between groups to bring tacit knowledge into the organization, or socialization within the organization to share tacit knowledge contained within it [2]. Externalization is the method through which tacit knowledge is converted to explicit knowledge, and commonly involves figures or sketches to develop an explicit concept or product from a collection of tacit knowledge. The combination method is then used to convert the explicit knowledge of individuals or groups into the explicit knowledge of the organization, commonly through the definition of common organizational systems or concepts. Finally, the internalization method is used to convert the organizational explicit knowledge into organizational tacit knowledge by making use of the explicit knowledge in organizational operations and implementation. By making use of all four methods of knowledge conversion, the tacit knowledge and experience of each individual is shared with the organization as a whole, allowing the organization to synthesize new knowledge through the combination of experiences and resources inside and outside of the organization.

### 2.2 Knowledge Creation Techniques and Theories

Nonaka maintains in [2] that there are five different organizational conditions that should be met to encourage organizational knowledge creation through the conversion process. The organizational conditions of intention, autonomy, fluctuation, redundancy, and variety help to improve the creation of knowledge within the company. To satisfy the condition of organizational intention, the overarching goals of the organization and the intent to achieve them must be made clear to the members. By maintaining an understanding of the organizations “knowledge vision,” members are able to determine the value and relevance of new or created knowledge. Once the organizational intent is established, individuals can productively function independently of the organization in the pursuit of knowledge creation. The ability of organizational members or groups to function independently is referred to as individual autonomy. An organization composed of autonomous groups or individuals seeking to create new knowledge will be more productive than an organization working as a single unit. Nonaka also focuses on the importance of fluctuations, communication, and variety within the organization. Accepting changes, or fluctuations, from outside or within the organization that require members to break common routines can result in members reevaluating established structures or beliefs to find more efficient solutions. By structuring groups within the organization to include redundant or overlapping functions and management, individuals are prompted to more fully understand the organization as a whole and can better share tacit knowledge across group boundaries. By increasing member access to information and diversity of member perspective, the organization can increase the knowledge base of each. This can be a measure of organizational variety, and allows for a more diverse base of tacit knowledge to be brought forth when solving problems.

In exploring the environment in which knowledge can be created and shared in an organization, [3] introduces the concept of Ba, a Japanese word meaning “space.” Nonaka explains that Ba is a shared space for the development of relationships and the creation of knowledge, defining it as a “time and space where knowledge, as a stream of meaning, emerges” [4]. The organization can be seen as an organic series of many different Ba, which are created, function, and disappear based on the need of the organization. Similar to the five conditions [2] introduced for enabling the creation of knowledge, synthesis of knowledge in the Ba can be stimulated by encouraging conversation between group members of different backgrounds and perspectives. The organization exists as a network of Ba that all interact, allowing members to view organizational problems from the perspective of an insider within their own Ba, or as an outsider interacting with a different Ba. As explained in [3], The Ba can exist in a variety of different forms which are outlined by Nonaka to include originating Ba, interacting Ba, cyber Ba, and exercising Ba.

Originating Ba is an environment in which members of the organization meet face to face to define ideas and mental models to begin the knowledge creation process [3]. In the originating Ba, the most common method of knowledge conversion is socialization, as members explain their feelings and personal interpretations of the problem at hand.
Bloodgood discusses in [5] how information technology (IT) can be used to aide in this process by communicating the location of tacit knowledge, and allowing communication between organizational members. Interacting Ba helps to support the process of externalization, in which peers work to define explicitly the mental models and concepts that originally existed as tacit knowledge in individual members. Through a dialogue between members, individual knowledge and experiences are converted into common terms and practices. The cyber Ba environment exists in the digital world, and serves most to combine explicit knowledge gleaned by individuals into explicit knowledge of the organization. Unlike the other forms of Ba, the cyber Ba can support interaction between many more participants, allowing an entire organization to interact in the Ba without limiting productivity. The exercising Ba is an environment in which the explicit knowledge of the group is converted to standard practice and routine, making it group tacit knowledge. Each of these Ba exists as a different space to provide members with the context to create and manage knowledge in the pursuit of the knowledge vision of the organization.

2.3 The Role of Leadership in Implementing Knowledge Creation

In defining the role of the leader in the knowledge creation process, Nonaka explains that “Leadership is about enabling the process of knowledge creation – not controlling or directing it.” [3] In the organization, it is the role of the leader to provide the resources and Ba necessary for the various groups to engage in the above processes of knowledge creation. Nonaka explains that the leaders of an organization are responsible for acting as knowledge activists, building new groups for knowledge creation and ensuring that they are connected within the organization, understand the organizations knowledge vision, and have the proper resources, variety, and access to information to enable knowledge creation.

3. Theoretical Model

Making use of the concepts of knowledge creation introduced in the literature, a theoretical model is proposed to encourage active knowledge management in the context of student design competition teams. The theoretical model of knowledge management focuses on developing strategies that will allow the leadership of these student organizations to employ active knowledge management systems that encourage the creation and documentation of knowledge. Through the use of these systems, knowledge created within the organization will stay within the organization, instead of leaving with each subsequent class of designers. By integrating active knowledge management systems into Nonaka’s four methods of knowledge conversion and enabling the five conditions for knowledge creation, organizational leaders will be able to capture knowledge in both explicit and tacit forms. In shaping the Ba involved in each stage of the knowledge conversion process, leaders will be able to enable conditions to encourage both the creation and active capture of knowledge.

To enable the socialization process, leaders will schedule organization-wide meetings or work groups, and encourage underclassmen to attend. Organization-wide meetings offer a space for the leadership to help shape and define the organizational intent, and share it with the organization at large. With a clear organizational intent, individuals are able to act more autonomously in their pursuit of knowledge. Additional meetings can be held between specific groups of individuals to ensure that all groups share tacit knowledge and the same knowledge vision. By working together in the same Ba, students will be able to share experiences and mental models that become common to the organization. Developing this originating Ba to include options to communicate with others face to face though common group meetings can ensure that tacit knowledge is shared within the organization and not simply between those involved in the senior capstone process. As discussed in [5], the originating Ba can also include digital options that can ensure socialization, such as a collective communication board or tacit knowledge sharing site. Methods of communication such as Skype, email, and other forms of digital communication can be used to simplify communication between busy students and advisors. By including digital communication options, the originating Ba also allows for outside knowledge from advisors and project partners to be heard and shared with organizational members.

Each member of the organization will be encouraged to engage in the externalization process, converting the tacit knowledge gained through socialization to individual explicit knowledge. The explicit knowledge gained through externalization can be used to shape concept generation and evaluation. To enable externalization, [2] suggests engaging in dialogue between members using metaphors, analogies, or sketches to express mental models and communicate concepts. The interacting Ba, in which the process of externalization takes place, can consist of conversations around a whiteboard or sketch pad, and will allow members to express different solutions to a common problem. The Interacting Ba should encourage different functional groups to communicate with each other to convert
tacit mental models into explicit design plans and procedures. By encouraging interaction across functional boundaries, the leadership can enable the requisite organizational variety, increasing the diversity of opinion involved in solving problems. Students will be encouraged to engage in the Interacting Ba by recording group knowledge using diagrams, pictures, or write-up sheets. By externalizing tacit experiences and knowledge using diagrams and descriptions of the experience, the students will be engaging in active knowledge management and producing explicit stores of knowledge that can be saved for future members. By designating space in a cloud drive for emergent designs and concepts, group leaders can encourage the active management of knowledge while keeping it available to all group members. Leadership should also encourage participation in the Interacting Ba by all groups, and make certain that the explicit knowledge created through the externalization process is able to be shared within the organization.

When converting explicit knowledge held by an individual to explicit knowledge owned by the organization, the method of combination is used. Combination of knowledge is arguably the most crucial method to engage in when concerned with loss of knowledge in an organization. By converting individual explicit knowledge into organizational explicit knowledge, ownership passes from the membership to the organization as a whole, allowing it to be accessed by future members. Combination can be enabled through the documentation of knowledge in either digital or written formats. Combination occurs primarily in the cyber Ba, consisting of interaction and documentation in the digital world. By moving this Ba into a digital plane, information can be readily saved and organized, with no limit on participants. A cyber Ba that is accessible by all members will add an element of redundancy to the knowledge management system, enabling all members to more easily share knowledge and better understand the organization. Leaders will encourage all members to engage in the cyber Ba, as it will be the foundation of the knowledge management system. By maintaining a cyber Ba complete with communication boards, group resources, project concepts and models, and document storage, project leaders will make the individual explicit knowledge of each project group available to current and future organizational members. Knowledge can be shared in the form of models, diagrams, pictures, videos, and reports. The knowledge system will reside in the Google resources made available by the school, and will be available to all members through their cloud based student accounts. A formal written report is already an expectation of the capstone design process, in accordance with the Writing Intensive Course (WIC) requirements, and will greatly help to lead future groups through design considerations. By encouraging interaction in the cyber Ba, the organization is able to actively capture the explicit knowledge created by each group, share it as organizational explicit knowledge, and convert it to tacit knowledge of the membership through implementation.

By implementing the knowledge learned through combination, the method of internalization converts the explicit organizational knowledge and processes into tacit knowledge throughout the organization. Internalization can be performed by practicing the procedures and knowledge gained through combination. Leaders can promote the internalization of knowledge by enabling the Practicing Ba, which will consist of collective lab spaces and build areas that will allow groups to build and develop their products. By providing spaces for building, testing, and recording results, groups can internalize the tacit practical experiences while actively documenting and saving explicit results in the Cyber Ba. By working with mentors and practicing learned concepts, group members will learn new concepts or encounter difficulties that will add to organizational fluctuation, as these issues will need to be resolved. Working to resolve problems will bring new knowledge into the organization, and enable group and individual autonomy as members work to pursue the organizational knowledge vision.

In working to enable the creation and management of knowledge, the organizational leaders should be focused on providing the five enabling conditions explored in [2]. The leadership will make the organizational intent known by driving the product concept selection and knowledge vision of the organization. Group autonomy will be preserved by defining the specific responsibilities of each group, and allowing each to work in pursuit of the organizational knowledge vision. Organizational redundancy and variety will be encouraged by co-locating groups in common Ba and encouraging them to share responsibilities and work when they are able. By encouraging groups to work collectively, tacit knowledge will be shared more readily across functional boundaries. Fluctuations within the organization will come from interactions between the groups as they work to integrate functional concepts into a final product. The leadership will facilitate these interactions by prompting each group to have plans for integrating their individual concepts with the product as a whole. A graphic model for the theoretical model can be seen in Figure 2 below, explaining the relations between various Ba and forms of knowledge.
By integrating active knowledge management systems into the knowledge creation methods introduced by Nonaka, the leadership of these student organizations can capture the knowledge created by the capstone design courses to advance future designs. The theoretical model introduced above has been applied in two case studies for the 2014 DBF and ESRA competitions, and is currently still being studied. The methodology and preliminary results of each is outlined below.

### 4. Case Studies

The below case studies introduce the two student competition groups that made use of this theoretical model. The details of how each team adapted the model and applied it throughout the year so far are outlined below.

#### 4.1 Design Build Fly

Oregon State University will compete in the Design/Build/Fly (DBF) for the second time in 2014. The DBF competition is hosted by Cessna and Raytheon and is organized by the Association of Aeronautics and Astronautics (AIAA). Each year there is a new mission profile is written for students. Students from up to 100 universities design and build an RC aircraft that can complete this mission profile. The teams also must complete a design report for their aircraft as part of their final scores for the competition. A model of OSU’s 2013 DBF plane is shown in Figure 3, this is very similar to the 2014 design.
Oregon State’s DBF team is broken up into four subsystems with a capstone group assigned to each subsystem. The four groups are aerodynamics, payload, propulsion/controls, and structures. In order for the team to be efficient the groups must transfer the knowledge that they gain through socialization, externalization, combination, and internalization. As a socialization method, the team uses weekly group meetings with the seniors and underclassmen chapter members in order to turn single tacit knowledge into group tacit knowledge. This also allows upperclassmen to share the knowledge that they have gained so that it will remain with the underclassmen for future competitions.

As an externalization method, the team writes a design report that describes the entire design and manufacturing process of the project. This document will be available for future teams to reference. The team will also create a library of photos and manufacturing tips so that future students will know manufacturing methods that do and do not work. As a combination method, the group has a website where they can post photos and information about what they are doing and what they have learned. All of this information will be collected and organized within available Google Drive space on the OSU network. On this drive, students will store the information and methods that were used during the project, and future teams will be able to reference this material. This Google site is the basis of the proposed system because it is where all of the documented information will be stored. It is also possible to measure the success of a Google site and determine how effectively the team is using it. This site can be locked to outside viewers and only shared with the team members in order to protect the information. Finally, as an internalization method, the team uses the build process. This is where members of the team meet and put all of the knowledge that they have gained into manufacturing a plane.

The team also requires a manager who is responsible for providing opportunities to create knowledge within the team. This is done through intention, autonomy, fluctuation, redundancy, and variety. The Oregon State DBF team has assigned two project managers to see that this is done. One of the managers focuses more on the manufacturing of the project, while the other focuses on the documentation and communication. The organizational structure of the team is shown in Figure 4. The leaders use intention by setting project goals and deadlines for the team. The leaders use autonomy by assigning individuals within the group to take ownership of specific parts of the project. This brings in new perspectives to the projects and allows students to gain knowledge through their own research and experiment. Fluctuation is accomplished by communicating with advisors and responding to outside opinions of the project. Redundancy is accomplished by encouraging interaction between the subgroups. Although each group is responsible for their own subsystem, the subsystems must all work together to create a successful aircraft. By discussing goals and designs with other groups, students will have a better understanding of the end product. Finally, the team accomplishes variety by listening to outside people, such as industry professionals or professors to seek out new ideas for their design.
4.2 ESRA Case Study

Oregon State University will be competing for the first time this year in the Intercollegiate Rocket Engineering Challenge (IREC). The challenge is hosted annually by the Experimental Sounding Rocket Association (ESRA), and follows the mission profile of launching a 10 pound payload of sounding sensors to a pre-determined height. OSU will be competing in the basic category, launching a rocket to 10,000 feet AGL. Points for the competition are based on Presentation deliverables, preparedness for launch, recovery operation, altitude attained, and amount of components designed and built by student participants. The conceptual design for OSU’s rocket is shown in Figure 5.

The conceptual design for OSU’s rocket is shown in Figure 5.

![Figure 5: Conceptual design of OSU’s 2014 ESRA competition rocket](image)

The OSU ESRA Project rocket is divided into the four functional divisions of structures and integration, controls and recovery, propulsion, and payload. Each functional group was assigned a senior capstone team and project lead. In order to ensure group autonomy, the lead of each group was made responsible for meeting the deliverables set by the capstone class and project manager. The project manager was made responsible for ensuring that project deadlines were met and that each group had the resources necessary to create, share, and manage knowledge effectively. The organizational structure of the team is shown in Figure 6.

![Figure 4: Organizational structure of OSU's DBF team](image)

It is the first year OSU will be competing in the IREC, making the acquisition of tacit knowledge a crucial starting point in developing the end product. Each group was assigned a mentor who was capable of meeting with group members to answer questions and share sources of knowledge. To encourage variety in the opinions available, weekly lead meetings were held in a casual setting to discuss functional implementation and integration. A group communication board was implemented in a project organizational app called Trello as well, allowing members to communicate what tacit knowledge they are able to bring into the organization. The Trello board allowed socialization options for members that were not able to attend meetings directly, and was able to capture organizational data and
communication. The organizational fluctuations recommended by Nonaka came from mentor and lead reviews, and served to force group members to re-evaluate solutions to meet project deliverables. Weekly all-team meetings were held to share new tacit knowledge with the team, and refine the organizational intent. Team meeting slides and minutes were recorded for future review.

During the externalization method of knowledge creation, the groups were encouraged to work with each other to develop concepts for consideration. This process commonly involved discussing mental models using metaphors or sketches, and happened both within groups and between group members. Meetings between leads were used to define how various components would integrate, and which concepts would function best within the rocket as a whole. The results of these discussions were captured in design review papers, outlining the different designs considered and reasons for selection. Involving all groups in the externalization processes together helped add to the redundancy and variety of experience explored by Nonaka as enabling conditions for knowledge creation.

To engage in combination, a google drive was created to organize the explicit knowledge created by each group. All documents pertaining to design selection and refinement in the externalization and combination methods was stored on the drive instead of personal computers to allow access by all members. Additionally, the Trello app was used to manage short term project deliverables and group communication. Each team was required through the capstone design course to produce a report detailing the considerations made throughout the design and build stages of the project, and each report was uploaded to the google drive. All sources of knowledge were ultimately synthesized and added to a collective model in SolidWorks to ensure integration. The Cyber Ba was developed to actively save and store the explicit knowledge of each team member, and share it with all others.

To internalize the explicit knowledge created by the groups, members of the entire team will be invited to assist in the build processes. By including not only other members of the senior capstone course, but also the underclassmen members of the AIAA, the team will help to turn the explicit knowledge of the organization into tacit knowledge within future team members.

![Organizational structure of OSU's ESRA team](image)

**Figure 6: Organizational structure of OSU's ESRA team**

5. Conclusion

The two case studies discussed above demonstrate a model of how student competitions can be successfully implemented as capstone projects. The projects will be most successful when a knowledge management system is implemented. This management system must be active and allow students to store knowledge as they are learning it. The system must also combine both tacit and explicit knowledge in order to transfer knowledge from year to year. At least one team leader will be required in order to enable opportunities for knowledge to be created, transferred, and stored.
At Oregon State University, the SAE projects have provided a model for the DBF and ESRA competitions. The members of SAE have created an extensive knowledge management system that has allowed the team to succeed during competition. As part of this system, they have an extensively organized parts catalog. The DBF and ESRA teams plan to use the SAE team as a model for future development and create a management system that will allow the teams to design and manufacture competitive projects.

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References