Linking Academic Theory and Industry Practice through Interactive Student Projects: A Case Study of System Dynamics and Product Development

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Abstract

The Bose Corporation and Massachusetts Institute of Technology (MIT) cooperated in an interactive project to apply system dynamics to product development. Bose and MIT participated at four levels: as individuals, as teams, as sponsors, and as organizations. The participants brought different but complementary objectives, perspectives, and abilities to the project. The MIT team consisted of three graduate students in the Applications of System Dynamics course at MIT’s Sloan School of Management. Several product developers and managers of Bose’s Systems Products Division participated. The teams used a tightly coupled combination of facilitated discussions and model-building to explore a current product development issue with the system dynamics methodology. The flexibility of the sponsors, teams, and project design allowed adjustments to both the project’s inherent ambiguity and an unexpected change in scope. The integration of complementary projects features and participant capabilities at several levels helped reach the goals of both the Bose and MIT teams. This paper reports on the project and participant features that linked theory and practice, and introduces a tool to describe and explain the project. A design for interactive projects could improve projects from both industrial and academic perspectives.

Introduction

Both industry and academia contribute to the advancement of industrial practices such as product development. Industry provides the problems to be addressed, the complexity of real-world practice, product development expertise, and test sites for theories and tools; academia educates and trains product developers and development managers, creates theories for improved understanding, and designs new tools for improved performance. Therefore, projects in which both industry and academia cooperate provide opportunities to link academic theories and industry practice for the benefit of both partners. Traditionally, applied research emphasizes the role of quantitative data collection and analysis and de-emphasizes the value of contact with practitioners. In contrast, projects that actively and regularly engage small teams of practitioners from industry with researchers and students from academia hold particular promise by focusing concentrated and complementary strengths on a shared issue. We will call this type of project an interactive project. The narrow focus and interpersonal contact used in interactive projects can reveal data and drivers of business processes that traditional project approaches may miss [e.g., Burchill & Walden, 1994]. Therefore, interactive projects warrant increased study.

Differences between industrial and academic partners in interactive projects can limit the success of such projects, raising several valuable questions. What characteristics of industrial and academic partners lead to successful interactive projects? What characteristics of interactive projects facilitate the fulfillment of the objectives of all project participants? How can participants in interactive projects behave to increase the chances of a successful project? This paper attempts to provide insights into these questions by focusing on the characteristics of the participants and process instead of on the technical content of the Bose/MIT project.

Bose and MIT participated in the project at four levels: (1) as individuals, (2) as the project teams formed by those individuals, (3) as sponsors of those teams, and (4) as organizations. At the most disaggregated level, individuals brought their own perspectives, objectives, and capabilities to their teams. Those individuals formed two project teams: a cross-functional team of product developers from Bose and a team of MIT students. The project focus that brought together the two teams was the use of system dynamics methodology [Forrester, 1961; Richardson & Pugh,
1981] to study product development. At the sponsorship level, two men directed the project to fulfill their own specific goals and the objectives of their organizations. At the organizational level, Bose and MIT were continuing a relationship rooted in their common history.

After the project was completed, the interface matrix (Fig. 1, below) was developed to investigate the interactions between Bose and MIT participants. The matrix shows all four levels of participation for each of three important participant features: their objectives, perspectives, and abilities. Each cell of the matrix represents an interface between project participants from Bose and MIT. For example, the cell at the intersection of “Organization” and “Objectives” represents the interface of Bose’s objectives and the Sloan School’s objectives as they relate to the project. We propose that answering two questions about each of the twelve interfaces identified by the matrix leads to an improved understanding of the project and the role of specific features.

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### An Interface Matrix Identifying Important Interactions Among Project Participants.

<table>
<thead>
<tr>
<th>Levels of Participation</th>
<th>Features of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Objectives</td>
</tr>
<tr>
<td>Organization</td>
<td></td>
</tr>
<tr>
<td>Project Sponsor</td>
<td></td>
</tr>
<tr>
<td>Project</td>
<td></td>
</tr>
<tr>
<td>Team</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 1*

Answers to the first question describe the condition of the interface:

How complementary were the features of the participants (matrix columns) from Bose and MIT at this level of participation (matrix rows)?

The degree to which the features of the Bose and MIT participants complemented each other reflects the opportunities and challenges presented by the project.

Answers to the second question describe the response of project participants to the condition of the interface:

How much effort was used to integrate the features of the participants at this level of participation?

The effort applied to integrate the features of the participants reflects the participants’ focus.

We propose that the relationships between the interface conditions and the participants’ responses to those conditions can help explain the project experience for its participants. A completed interface matrix will be used in the section of this article entitled “Reflections” to develop insights about the project. Throughout the project the participants actively applied their special abilities to seek out and effectively integrate their complementary characteristics to fulfill their own objectives and the objectives of others. The dynamic interaction of the project participants as they coordinated their strengths and weaknesses across their similarities and differences tells the story of the system dynamics project at Bose.

### Background

**The Organizations**

Several fundamental differences exist between Bose and the Sloan School of Management. The Bose Corporation is an integrated developer and manufacturer of sound system equipment. It is driven largely by a profit motive. Bose’s products are tangible retail goods, and its environment—the marketplace—quickly rewards Bose’s efficiency in bringing competitive products to market. That environment also forces quick adjustments in response to product development failures. In contrast, Sloan is a specialized branch of a university. It is driven by its education and research missions. Its educational services and research products are primarily intellectual. Sloan’s environment—students, faculty, and administration, for example—moves relatively slowly in rewarding Sloan’s production of quality graduates and new knowledge. The differences between these organizations are the basis for the opportunities and challenges of interactive projects between industry and academia.

Despite their differences, Bose and Sloan brought complementary perspectives to the project. Their histories, values, and positions within their industries shaped those perspectives. The histories of the two organizations predisposed Bose and Sloan to cooperate. Each had extensive experience working with organizations...
in the other’s environment. Therefore, they were familiar with the differences between industry and academia as well as with their potential in cooperative ventures. Both believed interactive projects could help them fulfill their objectives. Equally important, both Bose and Sloan had experienced varying degrees of success in previous interactive projects. They also had a long and successful history of working with each other. Dr. Bose, founder of the Bose Corporation, began his pioneering research work in acoustics as a graduate student at MIT. He had served on MIT’s faculty for several decades at the time of the system dynamics project. Sherwin Greenblatt, Bose’s president, became familiar with system dynamics while a student at MIT, in fact, he had spoken directly with Professor Jay Forrester, the creator of the system dynamics methodology. Greenblatt was therefore very open to system dynamics as a method of improving industrial practice. Bose and Sloan had cooperated through the research of individual doctoral candidates on several occasions. The strength of the relationship between Bose and MIT prior to this project both predisposed them to support the project and raised their expectations of what the project would produce.

Bose and Sloan also hold similar positions within their industries. Both are medium-sized organizations, both are considered world leaders within their domains, and both are famous for innovation. These similarities generated similar expectations for project contributions and benefits.

In addition to their perspectives and positions, Bose and Sloan also shared values such as the development of new knowledge and the application of that knowledge for profit. However, they differed in the priorities they assigned to those shared values. For example, the development of new knowledge about the product development process is a high priority for Sloan, since one part of its research mission is to actively generate knowledge about business operations. However, as a product innovator Bose actively researched and developed new knowledge about products. Thus, although it was natural for Bose to research and experiment with its business operations (to support its efforts to increase competitiveness), knowledge of business operations was only one of its supporting, or lower-priority, values. A complementary example is the applicability of new knowledge to industry practice. Applying innovation to operations is essential for Bose to meet its objectives. The applicability of its research is also important to Sloan. Shared values allowed the project to fulfill the objectives of both participants simultaneously. The mutual selection of project partners with similar values helped integrate their complementary features.

The history, positions, and values of Bose and Sloan shaped their objectives, perspectives, and abilities for the project. These three interfaces are represented by the top row of cells in the interface matrix (Fig. 1). Their shared or similar experiences and values created opportunities for effective communication. Their differences provided opportunities for each to uniquely contribute to and benefit from the project.

The Project Sponsors

The project sponsors reflected the values of their organizations and added their specific experience, expertise, and objectives. Richard Payning was the sponsor for Bose. As the director of new products, Payning was responsible for the development of integrated sound system products. As Bose’s representative to the system dynamics project he was responsible for protecting Bose’s interests, especially the sensitive information related to their product development process. He therefore sought support from Bose’s upper management before the project started. This would reduce the probability of losing internal support after the project had begun. Payning recommended the project to Bose’s president Sherwin Greenblatt largely on the reputation of Sloan and its project sponsor for professionalism and discretion about sensitive information. As an added precaution Payning and Greenblatt required nondisclosure statements from the MIT team and its sponsor.

For Payning the project was part of a much larger effort to change the very nature of product development at Bose. Those changes included developing organizational learning as a new core competency at Bose and becoming a learning organization, a major cultural transition. This project was part of Payning’s plan to build in Bose a critical mass of product developers who have improved “managerial technologies.” Developers applying these new technologies would see Bose as a whole and not as a set of functional parts. Payning wanted his product developers to use perspectives as broad as those of successful executives. He saw new ways for Bose product developers and managers to interact that would be critical to the quantum improvements he sought. For Payning, introducing of system dynamics at Bose was a means of changing the perspectives of some of those developers.

Payning himself reflected Bose’s philoso-
phy of using academic theory to build wealth in
the firm. He had recently sponsored an improve-
ment to Bose’s product development process
based on the research of a Sloan doctoral can-
didate [Burchill, 1993]. The reengineered pro-
duct development process improved the integra-
tion of Bose’s early product development. This success
inspired Richard to search for a method of re-
peatedly and reliably turning academic theory
into industry improvement. The system dynam-
ics project provided an opportunity to investigate
system dynamics as a possible tool for this goal.
By focusing the project on Bose’s reengineered
product development process, Paynting could
improve that process, expand on earlier improve-
ments, and investigate the acceleration of Bose’s
process improvement.

Professor John Sterman, director of Sloan’s
System Dynamics Group and the instructor of
Sloan’s Applications of System Dynamics
course, sponsored the project for Sloan. Sterman
believed strongly in the educational value of in-
teractive projects. He had used interactive
projects in his class. Prof. Sterman’s goals were
educational. He wanted his students to apply
system dynamics in the contexts experienced by
industrial practitioners. Although he was not
looking for research opportunities for himself,
he viewed interactive projects as potential re-
search sites for his students. Sterman was unam-
biguous and unequivocal: Any benefits to the
firm were secondary to the educational benefits
of his students. He reinforced this position to
Paynting: “This won’t cost your firm anything .
. . and there’s a chance you might get what you
pay for.” This outlook was based partially on
earlier experiences in which firms viewed
projects as a means of acquiring free labor from
MIT graduate students.

Professor Sterman initiated the system dy-
namics project by calling Paynting about Bose’s
interest in taking part in a project in Sterman’s
upcoming graduate course. Before the project
began, Sterman and Paynting had known of each
other only through mutual friends. Their initial
conversation was to be their only direct contact
throughout the project. Sterman described the
project, its objectives, and the role of the team of
MIT students. They discussed their expectations
and deliverables. Paynting expressed Bose’s se-
curity concerns. By the end of the conversation,
both sponsors were satisfied that their images of
the project were similar enough to proceed.

The perspectives of the two sponsors clearly
illustrate the potential differences in approaches
to interactive projects. The industry sponsor saw
the project primarily as a tool for initiating major
changes in his firm. The academic sponsor saw
the project primarily as a learning opportunity for
his students. The interface of the sponsors’ ob-
tjectives can be described in the Objectives–Project
Sponsor cell of the interface matrix in Figure 1.
The ability of the sponsors to find a shared image
of the project that could fulfill both sets of expec-
tations demonstrates the integration of different
but complementary perspectives. This interface
can be represented in the Perspectives–Project
Sponsor cell of the interface matrix.

**Project Risks**
The system dynamics project faced several large
risks, despite the foundation established by its or-
ganizations and sponsors. Those risks included:

- The members of the MIT team had not
  been selected. They remained un-
  known as a team and as individuals.

- The project image and objectives of the
  MIT team might differ from those of
  the sponsors.

- The MIT team might not meet the spon-
  sors’ expectations for professional con-
  duct. This could prevent the
development of trust by Bose and limit
MIT team access to product develop-
ment information.

- The Bose developers might be too
  busy or unwilling to participate in the
  project enough to meet the educa-
tional objectives.

- The Bose product developers and man-
  agers who would participate in the
  project as members of the Bose team
  were not selected. They remained un-
  known as a team and as individuals.

- The sponsors had high expectations.

- The project was defined only very gen-
  erally. The project’s scope and process
  remained unknown.

Most of these risks reflect uncertainty about how
complementary the Bose and MIT participants
would be at the Project Team and Team Members
levels of participation.

**The Project Definition Phase**
The project consisted of three phases: the project
definition phase, the problem description and in-
vestigation phase, and the project completion
phase. In the project definition phase, Alex Hou,
Don Seville, and David Ford voluntarily formed
the MIT team in September 1993, based on their
interests in product development. All three were graduate students at MIT. In addition to expertise in system dynamics, two members had product development experience, and one had project management experience. Hou, Seville, and Ford had not worked together before the system dynamics project. They received only a brief written description of the reengineering of the Bose product development process and of Bose’s desire to refine those reengineering changes. The MIT team would consider the project successful if they had a valuable learning experience, performed well in Sterman’s class, provided value to Bose, and created opportunities for extending the work for career development.

During the project definition phase the MIT team met weekly with Paynting and Tom Miller, Bose’s manager of transducers. Miller was a senior product developer and experienced troubleshooter at Bose. Miller’s special interest in system dynamics led Paynting to include him from the very beginning of the project. Miller played an important role both for Bose and for the MIT team. The initial meetings began by orienting the MIT team to Bose’s product development process, organization, and culture. Interviews, product and promotional demonstrations, and in-house publications augmented the discussions.

The orientation led quickly to explorations of product development issues as potential focal points for the project. These discussions developed a shared understanding of the critical factors for mutual success. The design of the project also began to take form in these initial meetings. For example, in one of their first meetings, Paynting described the refinement of the reengineered product development process for reduced cycle time. The MIT team described an academic model that could be applied to the issue in the form of a system dynamics model. Both Paynting and the MIT team agreed that the direction appeared promising and worthwhile but that the scope of such a project remained unclear. They agreed to consider what form this focus might take and to continue the discussion at their next meeting. In this way Paynting and the MIT team sought to simultaneously meet both Bose’s objective (to refine the process) and the MIT team’s objective (to build a model). The project focus was clarified and refined in many similar discussions between Paynting and the MIT team, and later between the Bose team of product developers and managers and the MIT team. This example illustrates the active search for a project design that matched complementary objectives. The interface matrix identifies this interaction with the Objectives—Project Team cell. Exploring potential goals for the project throughout several meetings—instead of during a single, long session—provided both Bose and MIT repeated opportunities to reflect on what they had heard and said and to adjust their perspectives and suggestions. The MIT team had learned the value of incremental progress, which they had applied in the problem description and investigation phase of the project.

The orientation and project focus conversations led to new discussions about and informal agreements on how to manage the project. These project management discussions allowed Paynting and the MIT team to share their constraints and to search for effective ways to direct the project. For example, discussions about balancing the project schedule, quality, resources, and scope revealed that two of the project variables were fixed: (1) The MIT team had to complete the project within three months, before the end of the semester; and (2) Paynting’s expectations for top-quality work were not negotiable and were matched by the MIT team. A third variable, available man-hours, was flexible within reasonable limits. But the fourth variable, project scope, would remain unclear for much of the project because of the nature of applied research. A project with three relatively fixed constraints and a fourth, unknown variable could be difficult to manage. Therefore Paynting and the MIT team agreed that the project scope would be adjusted if necessary to ensure a timely completion and that the MIT team would be responsible for monitoring and addressing this issue.

Paynting also used the project definition phase to evaluate the MIT team. To guide him in directing Bose’s participation in the project, he sought answers to several questions:

- How professional is the MIT team? Can they be trusted with sensitive information about Bose’s product development process?
- Does the MIT team or any of its individual members have objectives that differ significantly from Bose’s or Paynting’s own objectives?
- How does the MIT team’s image of the project compare with his and Sterman’s understanding?
- How committed is the MIT team? How well prepared, consistent, and cohesive is the team?

Some of Paynting’s concerns were addressed.
by MIT team member Don Seville. Seville participated in a product development project at Ford Motor Company. Paynting had worked with Ford Motor Co. through the Center for Quality Management and considered its project development challenges to be as difficult as those he faced at Bose. He had also heard that Ford had been pleased with the MIT program. Therefore, Seville's experience from the Ford project reassured Paynting that he could expect professional work from the MIT team.

Paynting and Miller played complementary roles with the MIT team. Paynting provided drive, vision, and a strong Bose perspective. Miller was quieter and more reflective. The MIT team consciously used Miller as a sounding board and interpreter of what Paynting said. The diversity of the MIT team also helped by bringing several perspectives and strengths to bear on each issue. For example, David Ford's background in project management invited monitoring and control issues, whereas Seville's group interaction experience emphasized development team makeup. This diversity accelerated the orientation of the MIT team to product development at Bose. Both Bose and the MIT team recognized the benefits of interacting with a diverse group and of leveraging that diversity.

Three important project features can be seen in the project definition phase. First, participants appreciated the authenticity and importance of the objectives and constraints of others, as illustrated by Paynting's acceptance of the MIT team's time constraint. Second, open and honest discussions early in the project developed direction and tools that were later used to make the project a success. (See the section entitled "Indicators of Project Success.") Third, the understandings developed in this stage of the project required trust and faith in others, such as Paynting's faith that the MIT team would provide the quality and project scope that would meet his expectations. The roles of trust and faith highlight the importance of Bose's relationship with Sloan and Paynting's relationship with Sterman in Paynting's willingness to take on this interactive project.

**Working In Teams**

As Paynting's confidence in the MIT team grew, he and Miller considered candidates for a Bose team to work with the MIT team. They considered the wise selection of Bose members to be critical to the project design. Paynting's primary criteria for selecting Bose team members were participation in the reengineered product development process and an openness to change. Also, both Paynting and Miller believed that a sincere interest was more important than availability at the time of the project.

These criteria identified some of Bose's leading product developers and product development managers as potential Bose team members. Paynting and Miller invited eight to ten developers to form the Bose team. Paynting described his project goals for each potential Bose team member. He also explained that the project's success or failure would be reflected in their improved understanding of organizational dynamics after the project. Joe Killough, a senior developer in Bose's Systems Concept Development group, and Ken Knapp, a product development manager in the Electronic Design and Development group, became core members of the Bose team. The time commitment and energetic participation of these men and the other members of the Bose team were critical to the project. Paynting planned to significantly reduce his direct participation in the project as soon as a Bose team was formed, thus minimizing any impression that the project belonged to him or was biased toward the functional groups that he supervised. Paynting hoped that by preventing these misconceptions, Bose would more broadly accept the results of the project. Paynting's separation from the project would also prevent any self-censorship instigated by the presence of a senior manager. Finally, Miller joined the Bose team and continued to assist with the necessary logistics, such as meeting rooms. Miller would act as Paynting's eyes and ears. The importance of such a link from the project to the sponsors became clear near the project's completion.

Meanwhile, the project definition phase had convinced the MIT team that the broader perspective of a larger Bose team was needed. Unaware of Paynting's plan, the MIT team recommended the formation of a team of Bose developers to work with the MIT team at regular meetings. The shift from the MIT team working with Paynting and Miller to working with a larger Bose team changed the tone and pace of the project and moved it from the project definition phase into the problem description and investigation phase.

**The Problem Description and Investigation Phase**

The project team used its initial meetings to clarify and refine the problem definition and to further narrow the focus of the project. Then the problem definition shifted as members of the
MIT team learned about Bose's product development at the practitioner's level. The project team finally decided to focus on coordination at the interface of the Systems Concept Development and Electronic Design and Development groups.

**Facilitated Discussions Change the Texture of the Project**

One method used in project team meetings to effectively link MIT's academic theory (system dynamics) to Bose's industry practice (product development) was facilitated discussions. Using loosely structured conversations, an MIT team member guided the teams toward defined meeting objectives to explore a product development issue or to describe a portion of the Bose organization or process with system dynamics. Typically the MIT team structured the discussions around problem definition and modeling issues. The facilitator used tools such as the Ladder of Inference for grounding assessments in data and the balancing of advocacy for honest investigation of assumptions to probe beyond the official descriptions of Bose's organization and process and reveal underlying driving structures [Dyer, 1987; Senge et al., 1994]. MIT team model-directed questions often identified previously hidden leverage points in Bose's product development process. The facilitated discussion format was a highly interactive approach to investigating product development issues. It was also a significant departure from the MIT team's original plan of using conventional methods of applying academic theory to industry practice, such as the analysis of quantitative data, interviews, and surveys. The MIT team adopted this nontraditional approach for several reasons:

- A specific problem focus had not been identified. Considerable discussion was needed to narrow the project enough to build a feasible system dynamics model.
- The product development process at Bose was very complex. The MIT team believed they would develop an understanding of the process more quickly by working with representatives of major portions of the process as a group than by meeting with them individually.
- The MIT team believed that the flexibility of a discussion format would help to identify and explore potentially important influences and effects that more focused methods would miss.
- The MIT team expected the interaction and synergy of multiple perspectives to produce more insights faster than would more conventional methods. This was particularly important because quantitative data was not available to verify the system dynamics model.
- Two of the MIT team members had experience in leading discussions, and so there would be fewer learning curve losses in adopting a discussion format.

Additionally, the facilitated discussion approach increased the quality of the MIT team's intellectual work. The qualitative and conversational nature of the data collected at the project meetings forced Hou, Seville, and Ford to meet without their Bose counterparts to plan, evaluate, and reflect together on the project meetings. By working alone at MIT as well as with Bose, the students generated ideas and insights unconstrained by the unavoidable biases at Bose. This process also accelerated the progress of the project, since project meetings were not used primarily as a time for reflection by the MIT team upon the data collected.

The facilitated discussion approach also brought disadvantages. The approach slowed the collection of data needed to build the system dynamics model. This delayed the beginning of model building and threatened the success of the project for the MIT team. The adoption of a facilitated discussion format also initiated a project management dilemma for the MIT team: how to balance their efforts between building a feasible system dynamics model and exploring product development issues. This challenge will be described in more detail in a subsequent section.

**System Dynamics Provides Tools for Effective Communication**

Another method that effectively linked academic theory and industry practice was describing portions of Bose product development with system dynamics. This method was effective for three reasons: (1) the tools provided a shared language between the industrial and academic teams, facilitating communication and learning; (2) the Bose team was already familiar with the subject (Bose product development) and could therefore concentrate on learning system dynamics; and (3) by describing currently relevant issues at Bose, the Bose team could better see the potential value of the system dynamics tools in its work.

An example is the use of causal-loop dia-
grams\(^1\) to describe the interdependence of quality and schedule, as shown in Figure 2, above. [Goodman, 1988; Morecroft, 1982; Richardson & Pugh, 1981]. Repeated application of the system dynamics diagramming notation and conventions in Figure 2 improved discussions of complex systems by providing a tool to describe pertinent aspects of Bose product development in a new way. For example, the variable names represent meaningful portions of Bose product development operations, and the balance between schedule and quality was a current and important issue for Killough, Knapp, and the rest of the Bose team. The use of tools such as causal-loop diagrams led to an improved understanding of the problem accessible only through the nontraditional interactive approach. This integration of an academic tool and an industry topic to develop valuable new knowledge illustrates the integration of perspectives and abilities by Bose and MIT participants at the Project Team level.

Basing the project design on parallel teams of practitioners and academics and on facilitated discussions for investigating a complex system made the system dynamics project very interactive. The discipline of model-building provided direction within this flexible format. This response to the project’s ambiguity and complexity was an important, conscious, and assertive step toward utilizing unconventional approaches to integrate complementary portions of the project.

An Unexpected Problem

The project teams spent the majority of their time together exploring the issues facing product development at Bose. Each meeting excavated a bit more of the structure underlying Bose’s prod-

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\(^1\) “Causal-loop diagrams (CLDs), or interconnecting feedback loops, are among the basic structural elements in systems that generate dynamic behavior [Forrester, 1968; Goodman, 1988]. Feedback loops are a closed path connecting in sequence a decision that controls action, the level of the system, and information about the level (or condition) of the system, the latter returning to the decision-making point” [Forrester, 1968; pp. 1–7]. Two basic types of feedback loops, reinforcing (positive) and balancing (negative), are used to explain the dynamics of complex situations [Forrester, 1968; Goodman, 1974; Randers, 1980]. Reinforcing loops promote movement, either growth or decay, by compounding the change in one direction. Balancing loops resist change in one direction and try to bring a system back to a specified goal or equilibrium state. These two simple structures can be combined into causal-loop diagrams in a large variety of ways to describe complex systems. An S in a causal-loop diagram indicates that the two factors move in the same direction; that is, as one variable increases, the other variable also increases. An O indicates that variables move in opposite directions; as one factor increases, the other factor decreases” [Burchill & Kim, 1993].
uct development process. The members of both teams considered this work to be beneficial, but the investigations were time-consuming. Each newly exposed aspect of Bose's product development system pointed to additional areas for valuable investigation. This delayed the project team from building the system dynamics model in its conceptual form, as the MIT team had originally planned. About halfway through the project, Hou, Seville, and Ford recognized that the project scope as described in the original project design exceeded the time available. They had underestimated the time needed to understand product development at Bose well enough to model it, the complexity of the model required to address the focal issue, and the time required to collect, analyze, restructure, and apply quantitative data. The system dynamics model would not be completed and verified before the end of the semester unless its construction began very soon. At this point Bose was fulfilling its objectives, but the MIT was in jeopardy of missing an important target.

The project dilemma could be broken down into three problems. First, jointly developing a conceptual system dynamics model would both curtail further investigation of important product development issues and take too long; therefore the teams needed an alternative model-building approach that would preserve Bose team participation. Second, Bose had little quantitative data that could be readily used for model verification, and so an alternative model-verification approach was needed. Third, the MIT team needed to accelerate the rate of progress toward producing a completed model to ensure completion by the end of the semester.

The project team responded by altering the project design to accommodate their current circumstances. The MIT team replaced their original approach of conceptually building the model with a design-and-verify approach. They started to build the system dynamics model outside of their meetings with Bose and to bring central portions of the conceptual model to the project team meetings for discussion. The team also began to discuss nontraditional means of verifying its model. Since the MIT team would be using its own mental model of Bose's product development and not the mental model of the Bose developers, it sought a means of verifying their mental model. Previous research by Ford had proposed a method of describing mental models based upon a hierarchy of beliefs and the relationships among those beliefs [Ford et al., 1993]. The MIT team decided to use this method to structure the already collected qualitative data and to describe product development at Bose. The description could then be reviewed and corrected by the Bose team to verify the MIT team's mental model. Hou, Seville, and Ford were frustrated that time was not available to more directly include the Bose team in building the formal system dynamics model. This constraint came from the team's decision to use meeting times to investigate product development issues and to collect enough information to build the model by the end of the semester. Over time the MIT team developed the idea of using a tutorial session to simultaneously verify model simulations with Bose team experiences and to introduce the model to Bose team members.

Addressing the unexpected problem described above taught the project participants the value of the flexibility which Paynting and the MIT team had built into the project during the project definition phase. That flexibility allowed the participants to alter the project design during the problem description and investigation phase. Focusing on outcomes instead of on means and trusting each other to meet shared standards proved to be effective approaches. The use of tools beyond system dynamics in the redesign, such as mental model descriptions, also illustrates the use of external and unconventional capabilities to address challenges.

The Separate but Related Process of Managing the Project

Managing the project was an activity distinct from the application of system dynamics to product development at Bose. Project management required a significant time commitment. The differences between the industry and academic participants greatly increased the scope and difficulty of managing the project beyond the requirements of a project in a single environment. Project management issues can be classified as the management of the participants' expectations of the project and the management of their experience of the project. Expectation management began during the discussion between the project sponsors and continued during orientation as Bose and the MIT team learned about the capabilities and limitations of system dynamics and Bose's product development process. These understandings took form in the project design. Experience management included addressing opportunities and pitfalls, such as internal Bose politics; transportation to meetings and other logistics; security issues; intermediate project documentation and reporting; and relationships
among participants and between this project and other Bose improvement projects.

The minimal structure provided by the project sponsors increased project management leverage and the level of required expertise. Paynting focused on the changes he hoped to see in Killough, Knapp, and the other product developers, not the project methods. He had enough confidence in his agreement with Sterman and in the results of the project definition phase to let the project team manage itself. Sterman saw the management of the project as part of his students’ learning experience. He provided advice and discussed project and client management in his class and in meetings with the project team. He recommended means of dealing with industry participants and of capturing project data and insights. Sterman also met with teams of students upon request and criticized their intermediate reports. But he never directly supervised the MIT team and strictly declined invitations to become directly involved with the project. The extent, importance, and challenge of managing the project in addition to doing the project work was a major lesson for the MIT team.

The Project Completion Phase

Realization of Benefits

In the final weeks of the semester the project transitioned from the problem description and investigation phase into the project completion phase. Bose and Sloan received tangible benefits from the project during this final phase, including a report and system dynamics model and presentations to Bose and the MIT class from the MIT team. The MIT team prepared two slightly different versions of a single report [Ford et al., 1993] for the two project sponsors. The Bose version of the report addressed issues that were important to Bose but beyond those required for the class, such as the MIT team’s reflections on Bose’s product development process, recommendations for possible improvement, practical limitations of the use of the work, and the description of the Bose team’s mental model of its product development process. The MIT team discussed several potentially sensitive issues at length during its preparation of the report for Bose. Its conclusions or recommendations might contain errors because of its limited contact with Bose. Some of the most valuable insights from the Bose team could become political liabilities within Bose for team members or its sponsor. The MIT team took special care to present a balanced perspective and to provide a context for the project results.

The MIT version of the report was presented to Professor Sterman’s class near the end of the semester. The content of the presentation was discussed with Miller before the presentation to prevent the disclosure of sensitive information. A final presentation to Greenblatt and other senior managers at Bose was also planned but was delayed on account of schedule conflicts and eventually abandoned since Bose was convinced of the project benefits without the need for a final presentation.

Bose also received several intangible benefits. The MIT team led an extensive tutorial of the final model with the Bose team according to the adjusted project design. The tutorial session provided model verification, project closure for the two teams, and experience with a formal system dynamics model for the Bose team. The tutorial sequentially added model structure and simulations to illustrate the depth and complexity of the model. Comparisons of model simulations and Bose team experience built confidence in model dependability and in the potential contributions of system dynamics toward improving product development processes. Experiencing the model structure and results led Bose team members to insights about interdependencies within the Bose product development process.

The facilitated discussions also generated valuable intangible benefits. The project meetings had provided a format for unique and valuable discussions among Bose team members about important topics they shared but had no opportunities to discuss under normal circumstances.

Indicators of Project Success

Paynting noticed changes in how members of the Bose team interacted as a result of the project with MIT. The perspectives of individuals on the development team shifted away from the defense of their functional domains and toward a global optimization of the product. The team continued making the project’s assumptions explicit and then questioning those assumptions. Paynting was impressed enough by these changes to initiate a pilot product development project using a new process within a few months of the completion of the project. Bose compared the time-to-market of this pilot project to another, simultaneously occurring product development project of similar scope and complexity. The time-to-market of the pilot project that used the system dynamics approach was approximately 50% of the other project. Paynting attributed about half of this improvement to learning curve
An Interface Matrix Describing the Project

<table>
<thead>
<tr>
<th>Levels of Participation</th>
<th>Objectives</th>
<th>Perspectives</th>
<th>Abilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Project Sponsor</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Project</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Team</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

**Legend**

Degree to which features of the Bose and MIT participants complement each other:
+ = complementary
0 = not related
− = uncomplementary

Relative level of effort to integrate the features of the Bose and MIT participants:
H = high
M = medium
L = low

Figure 3

and Hawthorn effects² and about 25% reduction in time-to-market due to the Bose/MIT project.

More subjective measures also indicate project success. The MIT team performed well in the class and considered the learning experience to be very valuable. Furthermore, the MIT team reached its goal of developing opportunities for extensions to the project. Seville and Ford made presentations about the project to professional and academic groups. Seville based his Master’s thesis partially upon additional research with Bose on how system dynamics could be applied more broadly within Bose. Bose became a potential site for Ford’s doctoral research work on the dynamic aspects of product development projects.

Bose internally evaluated the project near the its completion and found it to be a valuable part of their broader efforts to improve their product development as a firm. But some of the Bose team’s and Paynting’s objectives were fulfilled only after the completion of the project, when the performance of the subsequent pilot project could be compared to that of another project. Since the completion of the project, Bose team members describe their product development processes and team interactions as being different in more efficient ways. They assign partial responsibility for those changes to the project.

Bose also reported its evaluation of the project to Sterman. He considered the project to be both a good learning experience for the three students and the basis for future work by Bose and Sloan students. Also, the project reinforced the ongoing relationship between Bose and Sloan.

**Reflections**

**Revisiting the Interface Matrix**

The story of the project provides the information to answer the two questions presented in the Introduction for many of the interfaces identified in the interface matrix in Figure 1. The degree to which participants’ features were complementary can be qualitatively described with three values: complementary (+), not related (0), and uncomplementary (−). The relative effort applied to integrating features can also be described with three qualitative values: high (H), medium (M), and low (L). Based upon the project description and other project data, a portrait of the project can be drawn with the interface matrix (Figure 3, above).

The completed interface matrix describes a project condition and a participant response in each cell. The project condition of an interface (its complementary level) indicates fertile opportunities (cells with +), neutral impact interfaces (0), and areas vulnerable to interaction problems (−). The participant responses to these conditions indicate the level of effort made to positively use the interface condition. Highly leveraged interfaces are expected to occur when complementary conditions are enhanced with high integration efforts (i.e., cells with + and H), and vulnerable interfaces are expected to occur

²The Hawthorn effect attributes improved performance to increased attention on participants.
where uncomplementary conditions receive little integration effort (i.e., cells with − and L). High levels of integration effort are expected to partially compensate for uncomplementary conditions (H balances −) and visa versa (+ balances L). Interfaces with unrelated conditions or with medium effort are expected to be partially balanced and less influential than more extreme combinations of conditions and responses. Using these distinctions the interface matrix identifies three types of interfaces: leveraged, dangerous, and balanced. Describing the project with the interface matrix provides a method for identifying the nature of the influence of different interfaces on the project.

The top row of the matrix describes the supportive but passive roles of the two organizations. The complementary objectives of Bose and Sloan (useful and new knowledge), perspectives (shared benefits from different strengths), and abilities (theory and practice) created a supportive context for the project. The low effort to integrate reflects a flexible and trusting approach of both organizations toward the sponsors and teams. The complementary characteristics require relatively little integrative effort to prevent obstructions but also do not leverage the potential synergy in complementary features. According to the distinctions above, the three cells reflecting the interfaces between Bose and Sloan are balanced.

The second row of the matrix describes the interactions between Sterman and Paynting. They made little or no attempt to integrate their unrelated objectives (education and improved development). This created a balanced (but tending toward dangerous) interface cell. The sponsors focused their short interaction on integrating their perspectives of the project. The Matrix describes this as a balanced interface. The experience and abilities of the sponsors at directing interactive projects required little integration effort. Like the top row of the matrix, the strong and complementary conditions precluded a need for significant integration efforts, creating a balanced interface cell.

The interface matrix describes two of the project team interfaces (third row) as balanced. The complementary objectives (development of knowledge, value to Bose) were given medium level of effort, and the unrelated perspectives (theory and practice) were a focus of the team efforts. The "abilities" cell of the "project team" row is a leveraged interface. The complementary abilities (both high achievers) of the teams were leveraged by focusing project time on these interfaces with facilitated discussions. The team member level also is described with two balanced cells and one leveraged cell, with the characteristics and responses of individual team members being similar to those of the project teams.

Project descriptions and explanations based on an interface matrix that are applied only after a project is completed— as was done in this case—are vulnerable to confirmation bias, the tendency to retroactively emphasize evidence supporting an existing conclusion. Subjective assessment is also required to characterize a project with the matrix. However, the description reveals characteristics of the project that cannot be seen by inspecting the details or flow of the project. For example, the interface matrix contains two leveraged cells, twelve balanced cells, and no dangerous cells. This depicts a project with more strengths than weaknesses. Perhaps more useful than an estimate of project viability is the location of project strengths and weaknesses. For example, both of the leveraged cells use the abilities of the most disaggregated participants (teams and individuals). The two balanced cells that are closest to being assessed as dangerous (objectives of sponsors and team members) both address the objectives of individuals, indicating that the participants' objectives were an area of vulnerability for the project. Such project characteristics could prove useful if the interface matrix were used for evaluation and diagnosis during a project. The interface matrix may also be useful in planning an interactive project and identifying potential areas of leverage, balance, and danger.

**Lessons Learned**

The project participants learned valuable lessons concerning the drivers of the Bose/MIT project. The interface matrix facilitates placing the following individual lessons in the larger context of the project.

- All participants were respected and treated as equal members in a mutually beneficial project. There were no "leading" or "following" participants or a hierarchy of values, objectives, or constraints. Neither partner took a benefactor or recipient role, as often occurs in cooperative efforts between industry and academia. Participants actively sought to understand and address the objectives and constraints of all members in the project's design and management. For example, the MIT team was sensitive to the potential ef-
fects of the project or the final report on the politics within Bose.

- Shared values and objectives were not required for participants to meet their project goals. The stark difference between the fundamental objectives of the two sponsors vividly illustrates this point. Contradictory values appear to be a requirement, and complementary objectives increase the opportunities for attaining goals. Shared objectives also focused the efforts of several participants on the same goals, apparently increasing the effectiveness of participant efforts.

- Applying an issue-investigation approach to a theory-application project deepened the participants' insights. The modeling effort provided focus and direction for the flexible and sometimes digressive discussion format. Bose team members report that the modeling-based questions raised by the MIT team in the facilitated discussion format often lead to new and valuable discussions and perspectives of their product development process.

- Careful attention to project design and management at multiple levels of participation was critical. The management of the project was as much a part of the project as system dynamics or product development. Project management required experience and much time. Sponsors for both MIT and Bose understood the importance of project management and provided support and guidance within an open project structure.

- Flexibility was required to accommodate the project's ambiguity, complexity, and diversity of participant contexts, objectives, constraints, and perspectives. Building flexibility into the project design provided means of turning project problems into opportunities.

- Participants leveraged their unique and complementary capabilities to find innovative solutions to project challenges. They actively searched for ways to apply strengths from outside the strict boundaries of the project and accepted the challenges and risks of applying unconventional methods.

- Conditions and capabilities that preceded the project facilitated the project's progress and improved its results. As an example, both Bose and MIT brought fundamentally valuable contributions to the project: Bose brought an active product development practice and an openness about problems and operations, and the MIT team brought expertise in the system dynamics methodology and a commitment to produce valuable results for both partners. Parity of project needs and contributions apparently facilitated success in the eyes of the participants.

The time constraint of completing the project by the end of the semester was a significant factor in the progress of the project. A different project would have likely evolved after a few months had the MIT team consisted of professors or consultants and also had the Bose team had significantly more time available. We speculate that issue investigation would have continued for at least an additional month, eventually leading to a decision by the Bose and MIT teams to shift their focus to building the system dynamics model. If there had been enough time, the model might have been built interactively by the teams together (such a process is slow). A program of gathering quantitative and qualitative data for model testing might have led to specific policy testing and scenario planning for improved understanding of the effects of specific policies on product development performance.

**Conclusions**

The system dynamics project at Bose is an example of an interactive project between industrial and academic partners. The project was driven both by intentional actions and by unplanned circumstances, including the identification and integration of complementary features of the project participants and their utilization toward addressing project challenges.

The interface matrix can assist in describing and understanding interactive projects. The matrix may also be useful in identifying areas of high leverage, balance, and danger in the planning, diagnosis, and evaluation of projects.

The case study and interface matrix indicate that significant benefits can be gained from a model of successful interactive projects between industry and academia. A structure that facilitates the design and management of interactive projects and that can be adapted to various project topics and organizations would improve
the success of interactive projects between industry and academia.

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