Tangling with spaghetti : pedagogical lessons from games

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Tangling With Spaghetti: Pedagogical Lessons From Games

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Governments are seeking to develop entrepreneurial competencies among today's technology, science, and engineering graduates. However, the creation of "bilingual" graduates who have dual technical and managerial competencies is thwarted by students' inferior teamwork and interpersonal skills. In education, what is taught is inextricably bound to how it is taught (Dewey, 1916). Current pedagogies in engineering education are insufficiently adapted to student learning style needs (Felder & Silverman, 1988), and the management component of engineering education remains underdeveloped. This problem is keenly felt in one French engineering school where students struggle with a team-based innovation project. We detail efforts made to equip students with teamwork skills by using games as a pedagogical device. Student teams compete to build weight resistant structures using only spaghetti sticks and sewing thread. Their written feedback forms the primary qualitative data for this study. Individual student interviews were subsequently carried out to further uncover potential learning outcomes. We found that students' responses to the spaghetti game were overwhelmingly positive. Their commentary also illustrates concrete learning of many crucial teamwork processes. Finally, we discuss what makes this pedagogical innovation work and how it should be further studied.

"Education has no more serious responsibility than making provision for enjoyment of re-creative leisure; not only for the sake of immediate health but still more, if possible, for its lasting effect upon habits of mind"
—(Dewey, 1916: 167).

Technology management education concerns both engineering and business schools. During the past 30 years the number of academic institutions offering engineering and technology management programs and degrees has dramatically risen (Alvear, Rueda, Hernandez, & Kocaoglu, 2006). This growth relates to the fact that technology in the broadest sense has become a key driving force for firms, industries, and the global economy. Governments and universities worldwide are pushing for education programs that produce more "entrepreneurial engineers" who are "bilingual" in the sense that they possess dual managerial and technical competencies. Consequently, significant changes in engineering schools are required to prepare graduates for the challenges of the coming century (Carlson & Sullivan, 1999).

Developing entrepreneurial engineers means integrating lessons from entrepreneurship education into the engineering classroom. This may imply, for instance, developing both left- and right-brain thinking in students (Kirby, 2004) or opening them up to the world of opportunity identification (DeTienne & Chandler, 2004). Students' entrepreneurial mind-sets could be developed through increased exposure to creativity, critical thinking, initiative-taking, social networking, holistic management, and communication skills (Kirby, 2004; Gibb, 2005). Creating entrepreneurial mind-sets in students also calls for the use of innovative models and contents in teaching (Honig, 2004; Shepherd, 2004) and may involve changing the content of courses as well as the process of learning itself (Kirby, 2004). Entrepreneurship education is no longer the sole province of the business school academic (Kirby, 2004). Industry needs articulate engineers who can connect team members and their assigned tasks to the big corporate picture (Roman, 2006). Thus integrating entrepreneurial competencies into science- and technology-based curricula is one way to create more "bilingual engineers."

Today's corporations and employers frequently complain about the poor levels of communication and teamwork skills in engineering graduates (Felder, Woods, Stice, & Rugarcia, 2000) despite having team building and team working as core courses in many engineering and technology management programs (Alvear et al., 2006). This imbalance between what industry demands and what educational institutions provide (Dym, Agogino, Eris, Frey, & Leifer, 2005; Eskandari et al., 2007) may be due to *what* is being taught. In the United States, industry and educational experts were found to hold significantly differing views of key competencies for today's engineering graduates (Eskandari et al., 2007). However it may also be due to *how* the content is delivered. The how and what of education should be viewed as integrated issues (Dewey, 1916). Often engineering professors' traditional teaching styles are not tailored to match the common learning styles of students (Felder & Silverman, 1988). In the French case, students pursue rigorous preparation style classes in order to access the highly selective engineering schools. The focus is on individual rather than team-based work, and there is a heavy emphasis on scientific and mathematic principles delivered by way of the traditional "*cours magistral*" (or teacher-led, lecture-type lesson). This system promotes neither creativity nor teamwork at a time when the need for the "entrepreneurial engineer" is stronger than ever before (Goldberg, 2006).

Given the challenges facing engineering management education, an important question is "How do we effectively teach engineers with their predominant learning style in mind?" What teaching methods can be used to create entrepreneurial engineers that have a keen sense of teamwork? Despite the early adoption of an entrepreneurial point of view in engineering, pedagogical accoutrements have followed a more conventional path (Katz, 2008). While innovative teaching efforts may be in place, research into their use and outcomes is far from overwhelming (Wankat, Felder, Smith, & Oreovicz, 2002). Indeed, one can generally observe a distinct lack of studies addressing what makes pedagogical innovations work (Béchard & Grégoire, 2007). We suggest using games as a pedagogical device well suited to engineering students. It is considered an active pedagogical method (Benek-Rivera & Mathews, 2004) that can meet various learning needs (Eisner, 2004), and like simulations, can lead to generative learning (Zantow, Knowlton, & Sharp, 2005). Previous studies in the engineering arena with respect to the use of games tend to be descriptive in nature (i.e., Wang, 2001) or tend to compare hands-on games with computer simulations (Michael, 2001). Few studies actually substantiate the findings of previous empirical research on using games in the class environment (Azriel, Erthal, & Starr, 2005).

In this qualitative research study, we try to investigate whether using games can lead to significant learning outcomes for students in a French engineering school. The particular game chosen here—the spaghetti game—was introduced to first-year students in their first week of class. In our study, we tried to distinguish student-learning outcomes with a particular focus on teamwork skills. Many concepts and fields of inquiry may be used to examine the outcomes of using games in the classroom. For the present study, we drew on the educational science and team process literature.

Our paper is structured as follows: We begin by outlining the state of engineering education with particular reference to the French system. We present a brief overview of the team process literature and argue for the use of games as an appropriate pedagogical method to meet teamwork learning requirements. We then pose two research questions and present the game before outlining the research context and design. Our findings are reported in the Results section and analyzed using team process and education evaluation literature. In the final section we discuss our findings and outline some avenues for future research.

THEORETICAL BACKGROUND

Engineering Management Education

Engineering curricula have been based historically for the most part on an "engineering science" model, in which engineering is taught only after a solid base in science and mathematics (Dym et al., 2005). The resulting engineering graduates were perceived by industry and academia as being unable to practice in industry because of the change of focus from the theoretical to the practical (Dym et al., 2005). A general weakness in engineering education is the apparent mismatch or incompatibility of teaching methods with student learning styles (Felder & Silverman, 1988). The learning styles and expectations of today's generation are very different from earlier ones (Shaw & Fairhurst, 2008). Changing industry demands, societal values, and evolving student profiles have led to calls for more active learning techniques in the classroom (Benek-Rivera & Mathews, 2004) and also increase the need for more management education in engineering (Alvear et al., 2006). Today's students are thought to exhibit a different style of cognition: a short attention span and a preference for learning that involves exploration and discovery (Sauvé, 2000). Engineering students are typically active learners who learn through discussing, explaining, and testing in some way (Felder & Silverman, 1988). Their reasoning proceeds from particulars, such as observations, measurements, and data. They feel more comfortable with active experimentation and respond best to pictures, diagrams, flow charts, timelines, films, or demonstrations (Felder & Silverman, 1988).

Instructional methods and equipment open to engineering professors include lectures, labs, instructional technology, problem-based learning and active and cooperative learning (Felder & Brent, 2003). However, the predominant delivery method in most engineering schools today remains the "chalk and talk" or lecture method (Lamancusa, Jorgensen, Zayas-Castro, & Ratner, 1995; Felder, Woods, Stice, & Rugarcia, 2000). While the lecture is a longstanding, efficient technique for delivering large quantities of analytical information, it is not always the appropriate means to teach students managerial and entrepreneurial skills, elicit new behavior, or encourage action and interaction. Traditional instructional methods are not adequate to equip engineering graduates with the knowledge, skills, and attitudes required of them in the coming decades (Felder et al., 2000). They are not tailored to meet the particular learning style needs of engineering students. Failure to develop appropriate pedagogical methodologies may result in poor performance, professional frustration, and loss of potentially good engineers (Felder & Silverman, 1988).

In France, where this study has been carried out, the challenges of educating engineers are further exacerbated. The French education system has been criticized for its "elitist" tendencies, and engineering schools may be said to occupy a special place in the system (Barsoux & Lawrence, 1991). Highly ranked engineering schools are known for their rigorous selection process. Students often enrol in intensive 2-year preparation programs in the hope of joining such schools. These arduous "preparatory classes" involve rote learning and individual student exercises rather than team- or project-based work. The French engineering education system still predominantly favors the traditional lecture or "empty vessel" approach to teaching (Pepin, 1999), in which nonparticipative lectures to large groups of students are commonplace. In this context, students lack experience in teamwork and interaction. Engineering students are often rewarded for getting things "right" in the education system, yet it is experimentation and trial and error that are needed to produce and develop good ideas (Brown, 2007). The French system's preparatory classes are said to cultivate a risk-averse culture (Veltz, 2007) where student responses are either right or wrong. Aspiring entrepreneurial graduates must learn to use their imagination and not just to spit back a single "correct" solution (Stouffer, Russell, & Oliva, 2004: 8).

The Teamwork Challenge

In survey after survey, industry representatives place communication and teamwork at the top of their lists of desirable skills for new engineering graduates (Felder, Felder, & Dietz, 2002). A survey of 108 faculty and industry professionals across the United States revealed a significant difference between industry and education perspectives on what is required of today's engineers (Eskandari et al., 2007). While those involved in engineering education predominantly rated teamwork skills in fifth or sixth position, industry experts consistently rated it as one of the most important. Much of the work in today's organizations is completed through teamwork. Most engineering is done cooperatively, not individually, and interpersonal skills often supersede technical skills in getting the job done (Felder et al., 2000). A team may be defined as being composed of two or more members who (a) exist to perform organizationally relevant tasks, (b) share one or more relevant goals, (c) interact socially, (d) exhibit task interdependencies, (e) maintain and manage boundaries, and (f) are embedded in an organizational context that sets boundaries, constrains the team, and influences exchanges (Kozlowski & Bell, 2003). A successful team is not only a product of its members' talents but also of the processes that team members engage in to realize their goal (Marks, Mathieu, & Zaccaro, 2001).

A discussion of teamwork in the context of engineering education raises three important points. First, if teamwork is such a critical part of what engineers do, surely engineering schools should provide some guidance in how to do it (Felder et al., 2000). Second, as many organizational behavior lecturers can attest, teaching students how to "do" teamwork is no easy task (Goltz, Hiatapelto, Ewinaxh, & Tyrell, 2008). Students need exposure to phenomena before they can understand and appreciate underlying theory (Felder & Silverman, 1988). How can this be achieved here? Third, how can we better engage today's generation and simultaneously cater to the specific learning style of engineering students? We propose to use games as a useful and powerful pedagogical tool that can address these three concerns. The game we propose—the spaghetti game—implies active student participation in teams and departs from more common didactive teaching methods.

Using Games as a Pedagogical Tool

In 1958 Albert Schreiber wrote an article in the *Journal of the Academy of Management* about "another new teaching technique" which was said to offer "attractive possibilities for improved learning experiences" (Schreiber, 1958: 57). This new technique was the use of games. Using games in management education was originally an outgrowth of war games (Cohen & Rhenman, 1961), where the military had extensively used simulations to mirror real-world combat situations. Today, the entrepreneurship discipline draws heavily on developing and using simulations and experiential exercises as an integral component of the education process (Katz, Gundry, Low, & Starr, 1994). However, while business has integrated creativity initiatives since the 1930s, the engineering discipline has lagged behind in its integration of creative thinking principles (Brown, 2007).

There is a notable lack of definitional consensus concerning the use of games in education (Sauvé, 2000), and current research with respect to the use of games has remained fragmented and underdeveloped. A game may be described as an "artificial situation" in which players engage in an artificial conflict against one another or all together against other forces. Games are regulated by rules, which may take the form of procedures, controls, obstacles, or penalties (Sauve, 2000). These rules structure the participants' actions in striving to reach an objective. Game objectives may be concerned with winning or losing, about being victorious against others, or even about taking revenge on adversaries. Caillois (1958/1967) proposed that a game may be defined as a free, separate, and uncertain activity enabled though a controlled, yet fictitious context. Mauriras-Bousquet (1984) argued that teaching games should be bound to the program content and predictable for the teacher. They produce measurable knowledge, and while there are rules, games involving simulation go beyond fiction. In this article, we define a *game* as an educational device with discrete objectives with respect to the participants' learning, used in the context of known boundaries.

Experientialists believe that effective learning is an active experience that challenges the skills, knowledge, and beliefs of participants (Keys & Wolfe, 1988). Games and simulations are examples of active-learning techniques (Benek-Rivera & Mathews, 2004). Games can create "imaginary worlds and hypothetical spaces where players can test ideas and experience their consequences" Squire & Jenkins, 2003: 8). They create a student-centered environment (Sun, 1998). Their value lies in their ability to promote collaboration and peer learning (Ruben, 1999). They are said to be particularly appropriate for today's video-game generation (Benek-Rivera & Mathews, 2004). Games add to class variety and are a creative way to attract and hold students' attention (Benek-Rivera & Mathews, 2004).

Games and Teamwork

Games allow for practice in "reconciling different points of view among members in a team" (Schreiber, 1958: 52). They provide students with a creative environment that encourages them to work within a team, allows them to learn how to cooperatively interact with others, to communicate and problem-solve (Azriel et al., 2005; Benek-Rivera & Mathews, 2004). Games facilitate cooperative learning. *Cooperative learning* refers to any method which involves students working together to help one another learn (Murray, 1990). Games provide everyone with the same opportunities to get involved in an activity (Benek-Rivera & Mathews, 2004). Simulations, games, and role-plays are efficient and motivating ways to facilitate learning when changes in behavior are required as a result (Kofoed & Rosenorm, 2003). In the case of teamwork, doing it rather than listening about how important it is, is likely to have a more direct impact on student understanding. Yet teaching students teamwork is not an easy task.

Warner (2005) looked at the use of the "egg-drop" exercise and its effect on teamwork. The egg-drop game led teams to design, build, and price devices for protecting an egg from a 20-foot drop. It was found that the exercise did not help students build teams but was regarded as an entertaining ice-breaker, or way for students to get to know each other. The exercise helped the students function better in social terms, but team performance was built when students engaged in more demanding academic projects. Thus, Warner concluded that an exercise like this should not stand alone as a team-building device (2005) but instead be used as a complementary exercise.

Engineering professors have always experimented with innovative instructional methods, but traditionally little was done to link the innovations to learning theories or to evaluate them beyond anecdotal reports of student satisfaction (Wankat et al., 2002). However considerable progress in developing a scholarship of teaching and learning for engineering has been made in the last 2 decades (Wankat et al., 2002). Research has been done to assess the educational merits of computer simulations versus "hands-on activity" (Michael, 2001) and questions the effectiveness of computer simulations. Others are more descriptive in nature and outline the use of LEGO in instruction (Wang, 2001). The use of LEGO was found appealing to the students and provided an excellent medium for teaching design, programming skills, and creativity (Wang, 2001). Scant research has been completed with respect to the use and effectiveness of teamwork-building games in engineering education. Much of the recent discussion in the engineering literature focuses on how to assess learning outcomes, and relatively little has addressed how educators can equip students with the skills and attitudes specific to those outcomes, that is, teamwork ability, knowledge of science and mathematics, technical skills, and so forth (Felder & Brent, 2003). We attempt to investigate the use of games as a method of improving students' teamwork skills. We put forward the following research questions:

RQ1: *Are games an appropriate pedagogical device to meet the specific learning needs of engineering students?*

RQ2: *Can games help engineering students learn about teamwork?*

These questions lead us to one of the persistent problems in education: "How can pedagogical outcomes be assessed?" (McGehee, 1949). *Evaluation* is the study of whether the intervention works (Kraiger, McLinden, & Casper, 2004), that is, whether it produces the desired changes in participants' knowledge or skills. It is concerned with the accomplishment of learning objectives, the attainment of requisite knowledge and skills (Ford, 1997). We use Kirkpatrick's (1959, 1994) 4-level hierarchy as our frame of reference. This hierarchy is the most frequently cited (Alvarez, Salas, & Garafano, 2004) and perhaps the most influential framework in the field of education evaluation (Eseryel, 2002). Kirkpatrick's model is a 4-dimensional typology following a goal-based evaluation approach. According to this model there are four levels of student evaluation: reaction, learning, behavior, and results (Kirkpatrick, 1959, 1994). There is a hierarchical relationship among these levels, that is, a positive reaction will lead to improved learning, if learning objectives have been absorbed, this will lead to new behavior, and behavior in turn leads to results. While Kirkpatrick's work is not without its critics and has been berated for its simplistic and reductionist stance (Alliger, Tannenbaum, Bennett, Traver, & Shotland, 1997; Kraiger, 2002), Kirkpatrick's four levels remain important areas of scrutiny for those interested in evaluating pedagogical interventions. Our research questions are concerned with the evaluation of games; however, addressing all four levels is an ambitious task. We seek here to evaluate the game according to (a) student reactions and, (b) student learning, with a particular focus on teamwork-related learning. In the discussion section we reflect on the third level of analysis: behavior, that is, to what extent the pedagogical intervention results in behavioral change.

Below, we briefly outline the spaghetti game and our general research design, before presenting our findings in respect to the above research questions. Finally, we discuss our results and conclude by presenting some research avenues for future study.

RESEARCH DESIGN AND METHOD

The Research Context

The spaghetti game was implemented as part of a broader creativity and teamwork program initiative in an engineering school in Northern France. In the first year of their studies, students are expected to participate in a 2-year innovation project. This task addresses a "real-life" engineering project, which involves them working together as a team to respond to a realistic "client" need or opportunity. The project aims to mobilize entrepreneurial engineers who need to foster teamwork skills and innovation capabilities in order to succeed. The project is multidisciplinary, and project teams are expected to produce a concrete, technically feasible prototype as a result of their work. However, after several years of this program, teaching staff were confronted by the same recurring problems: students experienced problems of integration and team building (there were a number of isolated students), while others had significant problems of group dynamics (i.e., social loafing, conflict management, and general communication). Group projects were also generally low on creativity. A new initiative to combat these problems was launched that integrated creativity workshops, brainstorming sessions, and teamwork support. The spaghetti game was intended as an initial ice-breaker in the first week of class as well as an orientation to teamwork processes. Its exact workings are described below.

The Spaghetti Game

This game involves students working in teams to construct a bridge in round 1, followed by a tower in round 2 (see APPENDIX for a more detailed outline). Students are organized into preassigned teams and use uncooked spaghetti sticks and sewing thread as "construction" materials. This game was previously used to help training participants better understand the importance of experimentation and reflection in the learning process (Kofoed & Rosenorm, 2003). In this instance, our primary objectives in using this game were to open students up to the importance of teamwork. Thus, for the purpose of our research, some minor adaptations to the Kofoed and Rosenorm (2003) spaghetti game were made. Students are given a 20-minute recess break after round 1, and when they return, they engage in a 30-minute period of group discussion, or "debriefing" on their team's experience of bridge building. This debriefing is guided through several open-ended questions, and their written responses are later used as primary data. Introducing a gap between playing a game in its first rounds and in its last rounds evokes a remarkable difference in attitude and team ability (Lyles, Near, & Enz, 1992). An advantage of breaking up a game is that participants are allowed some time to think about what they have done correctly and incorrectly (Lyles et al., 1992). Incorporating a reflective aspect such as this to the game gives students the opportunity to improve their performance. The competitive aspect of gaming often spurs on this motivation. Following this 30-minute reflection session, students begin round 2 of the spaghetti game.

The spaghetti game—while modeling practical engineering concerns of structure, equilibrium, and interaction—was chosen for its novelty as well as its emphasis on teamwork. It was seen as a creative way to teach the students about an apparently abstract concept. It places heavy emphasis on active participation, and team members must work collaboratively to build the different spaghetti structures within the given time limit. Using spaghetti—a substance we usually associate with eating—to construct everyday structures holds a novel or "fun" aspect for students, which could capture their attention. The more fun and novel the activity, the more of a departure it signifies from previous pedagogical methods that they have experienced.

Study Participants

The participants in this study were 666 first-year undergraduates at a university in Lille, northern France. All participants were engineering students and were enrolled in a general purpose engineering program over a 3-year period (2006, 2007, and 2008). Student responses were collected from 111 groups (6 students each) over the 3-year cohorts. In each cohort, students were randomly assigned to groups, bearing two important conditions in mind: (1) there must be no more than one foreign student per group, and (2) students coming from the same high school or "preparatory" school may not be in the same group. All three cohorts were subjected to a similar recruitment process for first-year students, which entails an 85%–15% foreign student to home student ratio. The mean age of the students was 19.8 years old, and 22% of the population was female. The mean age and gender composition did not significantly vary across the three intakes.

Method

The methods followed in this research study adhere closely to Lewin Loyd et al.'s. (2005) classroom research paradigm and to Edmondson and McManus' (2007) vision of methodological fit in field research. Edmonson and McManus's framework relates the stage of prior theory to research questions, type of data collected and analyzed, and theoretical contributions. As previously mentioned, research investigating suitable pedagogical methods to attain requisite skills among engineering students is lacking (Brent & Silverman, 2002). Equally, accounts of the use and potential of games as a pedagogical tool are largely absent from mainstream journals. As such, we posit that we are in a nascent theory-building stage where "tentative answers to novel questions of 'how' and 'why'" are proposed (Edmondson & McManus, 2007: 1158). In line with this, we used a qualitative approach which means that we proceed with iterative adaptations as the research project evolves. We use theory from the more established fields of educational science and teamwork processes to help analyze our findings.

Data Collection and Analysis

We collected data in two stages. First, we gathered questionnaire data from 111 different groups over the 3-year period. Group "debriefing" forms were completed by student groups following each round of the spaghetti game and collected by attending teaching staff. All questionnaires were returned on the same day of the game. Students were asked open-ended questions about the group's atmosphere and organization, the division of labor, presence of a leader, team cooperation, and lessons learned. The groups' responses were saved as an Excel file (2006, 2007, and 2008) and later reviewed for recurrent or common themes.

First, student reactions to the game experience were categorized. Two researchers grouped responses according to teams' dominant impressions of the game and their groups' reactions to it. Among the group responses, three categories could be identified: (1) those who emphasized the fun and enjoyable aspects of the team's experience (64 groups), (2) those who adopted a constructive, worklike description of the team relations and task division/organization (29 groups), and (3) the minority who referred to some negative emotions of stress, feeling hurried, and seriousness (16 groups). The large majority of groups (93) reported positive aspects. These positive reactions are presented below in the findings.

As teamwork was our particular interest, we then further reviewed the responses to identify the emerging themes characterizing the group relations and team interaction. Working together, two researchers created 4 broad categories of response theme, and groups were allocated to one of these four categories (by each researcher independently and then cross-checking of categorization was carried out). The four broad categories found were (1) teams who referred predominantly to coordination and organization (59); (2) teams who recounted specific interpersonal aspects (20); (3) teams who mentioned both (28); and (4) those who did not refer to any team- or group-related aspects (4). From this initial overview, it appeared that team- and task-related learning had occurred. However, these initial responses were group based—thus perhaps prone to a common consensus bias—and needed further investigation.

Our second step involved interviews with students from the 2008 cohort. The interviews were held 3 months after the spaghetti experience, and at this stage students were actively engaged in their innovation project. Students are allowed to freely select their own teams. Some formed pairs or groups of three based on their spaghetti-playing team mates, but often students resort back to high school or preparatory school friends, roommates, or else formed a group based on a common interest. We selected four different innovation teams—a high potential team, two relatively average performing teams, and one problematic team—and e-mailed the team members to ask them to attend interviews. Eleven students responded. All interviews were conducted using a consistent set of semistructured questions and ranged in length from approximately 20–50 minutes. By using a consistent set of questions, we could compare and contrast the responses of the research participants across each topic. Students were asked to reflect on their social integration into the school, their impressions of the spaghetti game, and their current innovation project experiences. Following the interviews, both researchers read and reread several times the interview transcripts. Classification categories for coding the interviews were agreed upon by two researchers, three of which are of particular interest in this study: Spaghetti game reflections, social circle, and project team experience. We used the software package nVivo 8, which is a useful tool in qualitative studies to organize and analyze complex unstructured data. It also allows for efficient code comparisons between researchers. Each researcher then worked independently to assign student statements to the respective categories (tree nodes), and a code comparison check was run. The agreement between the two researchers' coding was 97.36%. A common theme running through the interviews was the respondents' references to teamwork. The respondents' description and interpretation of teamwork displayed many dimensions. Students had definitely learned about teamwork but what exactly had they learned? The literature on teamwork provided some guiding themes to help further analyze our student responses. Marks et al.'s (2001) teamwork process taxonomy shed particular light on our students' new understanding of team functioning. We subsequently created subnodes in the spaghetti and project team reflections. These subnodes were based on students' commentary relating to interpersonal processes, transition processes, and action processes within their teams.

In the paragraphs below, we go back to our original research questions and present our findings before developing related discussion.

RESULTS

RQ1: Are games an effective pedagogical device to meet the specific learning needs of engineering students?

In line with level 1 of Kirkpatrick's evaluation model (1959), we sought to gauge students' reactions to the pedagogical experience as a first step to querying its effectiveness as a pedagogical device. Below, we present student perceptions of the spaghetti game, their initial feelings, and reflections. Generally, students were extremely positive about their experiences. When asked to describe the general feeling of their group in the tower-building exercise, group responses were resoundingly positive:

"great, cool, perfect, excellent!" (Group 1B08), "good communication, good atmosphere, conducive to work, everyone was open to ideas, no problems even when we failed" (Group 1G08), and "good atmosphere, good mood, warm, a laugh" (Group 3A08).

Some teams also expressed a competitive or serious side to the fun. Their experience was

> "Calm, sociable, not too serious (but a little bit all the same!), warm, nice, relaxed, entertaining" (Group 4D08), or "harmonious, competitive, fun, (with a) good combination of ideas" (Group 3B08), and "good atmosphere, serious, studious and concentrated" (Group 1F08).

In the interviews, students from the 2008 cohort were asked to reflect back on their experience of the spaghetti game. Yet again, students had largely positive remarks:

> The spaghetti game was really cool, it's a good memory from the start of the year . . . it was funny. (MF)

> It was fun, a welcome change, a nice way to pass the time. (SG)

> The playful aspect was cool . . . nobody around me said it was dumb . . . Overall there were positive feelings about it. (GP)

These feelings were made especially clear when compared to other pedagogical interventions which were perceived as less guided, for example, a brainstorming session the students were involved in. In the interviews, students compared the two initiatives:

> I found the spaghetti game constructive, but not the brainstorming because with the brainstorming session we didn't really know the objective. (GP)

> (The spaghetti game) helped us get to know people. . . . I know a few people now thanks to this, and it also allowed us to play with spaghetti for 2–3 hours and that gives us a first taste of what it's like to work in a group . . . I found (the brainstorming) a complete waste of time. (AH)

However, students saying that they liked a pedagogical experience is one thing (reaction), but revealing what change the experience brought about (i.e., learning) is another. Level 2 of Kirkpatrick's (1959) hierarchy focuses on the learning gained from the pedagogical experience. From the debriefing, we see that lessons learned included the need to

> "Listen, without neglecting ideas . . . (to) communicate and avoid being narrow-minded" (Group G1206), "favour dialogue, compare and contrast different ideas, taking all suggestions into account" (Group 2F08), "to trust others, benefit from their experience while remaining critical, . . . refuse to reject others' ideas without having tested them and avoid imposing one's own" (Group G3606).

When prompted about their learning, students continually referred to team-related aspects. But what specifically did they learn about teamwork? Are they putting it into practice? Here we turn to our second research question and demonstrate that the spaghetti game did in fact help students learn some concrete lessons about teamwork, which they currently refer back to when discussing their innovation project.

RQ2: Can games help engineering students learn about teamwork?

Teamwork is multiepisodic and characterized by many subprocesses (Marks et al., 2001). A closer analysis of the debriefing and interview responses reveals that students were exposed to many critical team processes (Marks et al., 2001). Groups self-reported on the interpersonal processes at work in their teams (see Table 1). Evidence of awareness with respect to conflict management, team motivation, and confidence building as well as affect management was revealed. Students also mentioned the importance of various different action processes, that is, monitoring progress toward goals, systems, and team monitoring, back-up behavior and coordination. Transition processes, that is, mission analysis, formulation and planning, goal specification, and strategy formulation also appear in their commentary. Our findings with respect to student learning in these three teamwork processes are more fully outlined in Table 1.

DISCUSSION

Evaluation is concerned with whether the pedagogical intervention worked (Kraiger et al., 2004). In this instance, we feel that the spaghetti game did indeed work. First, it elicited resoundingly positive reactions from the participants. Students described the game as fun and interesting and found it a pleasant way to pass the time. Its form and

TABLE 1
Teamwork Processes

Teamwork Process (Name & Key Behaviors/Actions)	Group Debrief	Interviews
Transition processes		
Mission interpretation, problem evaluation and analysis; formulation and planning; goal specification; strategy formulation	"You have to designate time for planning . . . you need to start by clarifying the subject." (Group G1206) "It's essential to plan the entire project and to clearly define roles to optimise efficiency." (Group G2906) "It's worth spending some time planning, you should develop alternatives." (Group 1A07) "First off, a consultation session . . . which shouldn't last too long . . . to find the technical solutions to the project spec." (Group 5E07) "You need to decide from the very outset what will be done, and ensure that everybody has understood." (Group G106)	"You have to clearly divide up the roles." (GP) "Everybody contributed several ideas . . . at first, we brainstormed, we spoke about a lot of different things, everybody did something, then we chose the ideas that could work." (REK) "We had to find solutions very quickly, we had to decide quickly which solution to adopt . . . . basically it's a small-scale project in two hours." (SW)
Action processes		
Monitoring progress toward goals; systems monitoring; team monitoring & back-up behavior; coordination	"You need to keep the objective in mind . . . to keep an overall vision of what needs to be done." (Group 4E07) "(You have to) manage time, divide the tasks, plan and test the resistance in time to decide if that is the strategy you are going to pursue or not." (Group 2G07) "(You have to) know how to establish the problem specification, stick to it but also evolve according to the problems encountered along the way." (Group 2E07) "(It is important to) forecast and manage the material, manage time well and avoid waste." (Group 2E08)	"There are sometimes people who put forward ridiculous ideas . . . so you need to know how to channel that." (GP) "Working in a group of 6 or 7 was not always easy. You have to divide up the work well, you have to deliver . . . . we knew which (ideas) didn't work because we had already tried them, we chose the best and got it!" (REK) "We had a certain number of constraints, an objective to achieve, then (we have to think about) how to do (the task) considering the constraints and the time that we had . . . it's (about) balancing constraints and effectiveness." (AH)
Interpersonal processes		
Conflict management; motivation and confidence building; affect management	"(We need to) listen, without neglecting ideas . . . (to) communicate and avoid being narrow-minded." (Group G1206) "(You should) favor dialogue, compare and contrast different ideas, taking all suggestions into account." (Group 2F08) "To trust others, benefit from their experience while remaining critical, . . . refuse to reject others' ideas without having tested them and avoid imposing one's own." (Group G3606)	"The spaghetti game wasn't about technical know-how, we didn't have that . . . nobody had ever made a bridge or Eiffel Tower out of spaghetti before . . . . I don't think it was about who could build the strongest bridge . . . it was just about teaching us how to talk (to others) . . . we learned how to avoid personality conflicts between group members." (REK) "It was a good way to show us how to work in a team, to know how to present our ideas, and to see how others react when they are . . . left to solve a problem together." (SW) "Everybody had their own ideas and so at the very least it taught us how to listen to others." (MF)

objectives appealed to their desire to experiment and their need for hands-on practice, exchange, and discussion (Felder & Silverman, 1988). We believe that the positive reactions to the game also relate to its novelty as a pedagogical device. Its break from previous learning experiences contributed to its success and appeal.

"I found the spaghetti game . . . well, obviously it was fun . . . I think that was the objective, along with teamwork. . . . in *prepa*[1] we work in-

[1] "*Prepa*," short for the French '*Classes Prepa*' or '*Classes Préparatoires*'.

dividually or in groups of two or three but it's always written work . . . so this was fun." (WA)

> "I think that it worked because it wasn't actually formal. We played about with spaghetti sticks basically. It's not like there was something really rigid to do. It's a kind of game and I think this is motivating . . . because at the start of the year we're just back from holiday, our minds are elsewhere and so it's cool. It's not like we've got homework on the table and we've got to write it up." (GP)

> "It was a game, I don't see it like a class, we learned stuff but it's not the usual scholarly approach." (SG)

While the game was viewed as a departure from usual teaching practice, it was still credible enough to motivate students (Hindle, 2002). Using unfamiliar material, that is, spaghetti sticks (rather than LEGO) pushed students' limits. "Creativity, or the ability to see the world anew, making the strange familiar and the familiar strange, can help infuse a sense of purpose in education and help students learn to appreciate and work within the big picture" (Stouffer et al., 2004: 10). Our use of spaghetti as building material lured students deeper into "play" mode. It is thought that in doing so, their traditional learning experiences and expectations were suspended (Winnicot, 1975).

Eliciting strongly positive reactions from participants toward a particular pedagogical intervention is a first step toward activating their learning (Kirkpatrick, 1959). We believe that their transition to learning is not always a conscious one. In fact, the novel and playful aspect of games means that students are not always immediately aware that they are used as a learning device. For Winnicot (1975), playing is essential for transitional experience, where one can unconsciously change her/his previous perceptions of rules or reality. In the learning cycle (Kolb, 1984), students experience an initial exploratory phase. The nonrational nature of this phase is of extreme importance to initiate new discoveries and new learning spaces (Kolb & Kolb, 2005). The playful dimension facilitates open unbounded explorations, whereas later learning phases (reflection on practice, conceptualization) transform first discoveries in new conscious rules (Kofoed & Rosenorm, 2003). This is in line with Dewey's belief that the educational growth that emerges from play is often accidental (Dewey, 1916). Winnicot (1975) insists on facilitating conditions for such experiences to occur: Games are one way in which new truths can be unconsciously discovered.

With the passing of time, some reflection, hindsight, and more group work experience, the game's learning value became more apparent to students. When we interviewed students 3 months later, their perception of the game's value seemed clearer:

> "What's the objective? Build the highest tower . . . or the strongest bridge? But in fact, no, the goal is to work in a team but at that time, we're not aware of it." (MC)

> ". . . the spaghetti game (is) . . . a first approach, an introduction to teamwork." (AH)

Thus, based on our results, we believe that games can serve in technology management education as more than entertaining pedagogical devices. First, through the fun and interest that games generate among students, they can increase satisfaction levels and consequently student learning performance (Rode et al., 2005). By helping students develop stronger connections between course goals and content, students' game experiences can promote more durable learning (Zantow et al., 2005). Second, games constitute powerful devices for students to experiment with both action and experiential learning. Working within teams in the game process enables student participation in leadership and decision making at all levels and in multiple instances, so they can develop a form of collaborative leadership (Raelin, 2006). Finally, games can in fact translate into real learning outcomes. In this instance we showed how the spaghetti game helped expose students to the realities of teamwork. Student debriefing and interview commentary provided specific evidence of learning with respect to many of the ten critical teamwork processes (Marks et al., 2001). Thus games can go beyond merely assisting socialization and are more than a simple ice-breaker (Warner, 2005). Games can actually expose students to crucial group dynamics and increase their understanding of teamwork and team building. These lessons resurfaced in the students' discourse when describing their innovation project team's functioning.

Research Limitations

While we highlight the positive aspects of using games as a pedagogical tool in engineering management education, we view the above study as a preliminary research step. Our research is not without its shortcomings and limitations. Some groups reported negative emotions while playing the game. Such reactions were not dominant, however, and failed to resurface in the interviews, thus this negative perception of games for some students was not further explored. While we have rich qualitative data from the interviews that illustrates student awareness of team processes in their current innovation project, the information collected does have its limits. Whether student learning translated into real behavioral improvements is an important consideration, but such causal relationships cannot be observed from our current data. We must also acknowledge here the numerous criticisms of Kirkpatrick's assumption that positive reactions to a pedagogical intervention feed into learning and that that learning then translates into new or changed behavior (Alliger et al. 1997; Kraiger, 2002). Indeed the relationship between reactions, learning, and behavior is a more complex one. Thus more additional qualitative work, that is, observing teamwork in action before and after such interventions could provide enriched insight. Quantitative work could more precisely probe causal relations between students' learning and their experience of the game. The addition of a longitudinal dimension to such a study would add to its validity. Reflection is a key part of the learning process, and while we did revisit student perceptions of the spaghetti game 3 months after their experience and tried to interview students from diverse project teams, we acknowledge that our interview sample was too small to provide confirmative results.

Finally, we also acknowledge the lack of a control group in this study. There are many problems associated with conducting tight evaluation research on teaching efforts. Students cannot always be randomly exposed to different treatments; extensive evaluations of behavior and results are often not feasible, and holding factors constant such as class size, instructor and other subject enrollment is not always possible (Shaw, Fisher, & Southey, 1999). In this case, all students in the 2006, 2007, and 2008 cohorts were exposed to the spaghetti game. One way to counteract this problem is to gauge delayed reactions to interventions and collect all student feedback (Shaw et al., 1999). In this study we collected all group responses (111 groups in total) from the 3-year period and carried out interviews with 11 individual students 3 months after their initial game experience.

CONCLUSION

Engineering management education today needs rejuvenation and change. What industry demands, current engineering curricula do not deliver (Eskandari et al., 2007; Dym et al., 2008). Graduates are often found to be lacking in teamwork and interpersonal skills (Rugarcia et al., 2002). Equally sad, many engineering classes of today are taught in exactly the same way that engineering classes in 1959 were taught (Felder et al., 2000). Engineering students have a preference for active pedagogies which allow them to experiment and discuss (Felder & Silverman, 1988). Using games is one such pedagogical method that enables active participation. The use of games enables collaboration and peer learning (Azriel et al., 2005; Ruben, 1999), challenges students' skills and beliefs (Keyes & Wolfe, 1988), and can bring about behavioral change (Kofoed & Rosenorm, 2003). Games are also especially appropriate for today's generation, given their entertaining and novel aspects (Benek-Rivera & Mathews, 2004), and more particularly, to engineering students who respond poorly to passive pedagogies (Felder & Silverman, 1988).

In this instance, we used the spaghetti game to address students' inadequate teamwork experience. We found student reactions overwhelmingly positive and attribute this to the game's active and novel nature. We posit that the game enticed students into a period of nonrational and unstructured "play." Dewey (1916) believed in the often "accidental" output of educational growth through play. Students enter a transition period where they can construct and reconstruct new truths (Winnicot, 1975/2000). This particular game helped give students a real exposure to teamwork processes. They demonstrate learning related to action, transition and interpersonal processes of teamwork, learning that their previous educational experiences—individually evaluated performance and largely didactic teaching methods—did not favor.

We do not wish to present the use of games as the "one best way" to teach engineers and other scientific or technology students, but rather as an alternative method that can be used in combination with other pedagogical devices. In addition, we acknowledge the diversity of games. Different games can be used with different teaching objectives in mind. We posit that game-like activities could be used as a means to overcome other obstacles blocking the emergence of entrepreneurial behaviors and skills among today's engineers. We feel that further research looking at instructional games and their ability to influence creativity and imagination, stimulate original and innovative ideas, or alter risk-perception is warranted.

APPENDIX

SPAGHETTI GAME DESCRIPTION

Round 1: Bridge Building

Objective:	To build a bridge between two tables (which are placed ½m apart). The bridge must be capable of bearing weight. The winning team is the team with the strongest bridge.
Logistics:	Students are preassigned to groups. Each group has to build a bridge using the materials provided. The game is arranged as a competition between the groups—at the end of the allotted time (45 min), the newly built "bridges" are tested to see what weight they can hold.
Material:	(Per group) 2x 1kg spaghetti, 2x 500m sewing threads. For result "measurement": tape measure, scales, weights (5x 100g, 500g 1kg and 2 kg), a weight holder (plastic bag) which can be placed under the bridge.
Directions:	Build a bridge spanning two tables. The distance between the two tables must be 500cm. The bridge must rest on each table top. Students are permitted to place a hand on each end of the bridge where it touches the table.
Measures:	The strongest bridge is defined by its capability to carry the maximum load in 100g weights. The weight that each team's bridge can support is recorded on the whiteboard.

End of Round 1

Round 2: Tower Thrills

Objective:	To build a tower made of spaghetti that is at least 500cm in height and which is capable of bearing weight. Again the winning team is the team with the strongest tower.
Logistics:	Students continue working in their preassigned groups. Each group has to build a tower using the materials provided (as before). Similarly, at the end of the allotted time (45 min), the newly built towers are tested to see what weight they can hold.
Material:	(Per group) 2x 1kg spaghetti, 2x 500m sewing threads. For result measurement: tape measure, scales, weights (5x 100g, 500g 1kg and 2kg), basket for the weights which can be placed on top of the tower.
Directions:	Build a tower which is 500cm in height. The tower is placed on the table top.
Measures:	The strength of the tower is measured by placing weight in the basket holder at the top of the tower. Each tower's carrying capacity is recorded on the classroom whiteboard. The strongest tower is the tower which can carry the heaviest load.

End of Round 2

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