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Using the Contextual Skills Matrix for PBL Assessment*

WILLIAM COCKAYNE, JOHN M. FELAND III and LARRY LEIFER
Stanford Center for Design Research, Stanford University, Stanford, USA.
Email: gohogs@cdr.stanford.edu

This paper presents a tool for assessment of engineering skills and knowledge, based on a model of taxonomic classification. The tool methodology is built on previously published research and usage in the area of human performance measurement. The paper presents the development of the classification and its application in a comprehensive problem-based learning program in the School of Engineering at Stanford University. Examples are given to illustrate how the tool can be used to communicate the skills, create a common language and foster the creation of trust in teams within the PBL environment. The paper goes on to describe additional usage by faculty, students and industry practitioners in education and career planning.

THE VALUE OF TAXONOMIC SCIENCE TO PBL

PROBLEM-BASED LEARNING has moved to the forefront of engineering education, in practice if not in name. The present-day offering of problem-based courses exist under many names: capstone courses for undergraduate seniors; project courses that span multiple quarters or semesters; courses built around industry-sponsored research or design; and the most recent trend for creating entrepreneurship programs focused on the student creation of 'fundable' companies. A large number of today's engineering students, both graduate and undergraduate, will participate in at least one PBL course.

The growth in PBL programs has brought together an academically diverse group of professors, researchers and administrators, each with their own methods, knowledge and learning goals. Therefore, a critical issue in the creation and development of a PBL course becomes the definition of required base knowledge and learning. Put simply, current PBL courses must define the skills a student needs before starting the class, the skills that will be developed during the class, and the learning goals (new skills) that they expect to be graded upon. This paper addresses the problem of an uncodified skill knowledge base through the development of a taxonomic classification.

In any field of new or advancing learning, it is often difficult to find the common ground on which to construct a useful dialogue. In such situations, a classification can help in framing a problem area and providing the common ground on which to discuss implications. Classification is based on the ability to generalize across events, an important goal of science, and for establishing and enhancing communication among participants: learners, educators and others [1].

This paper presents the development of an engineering skills classification in multidisciplinary settings. This classification was developed for use in team-based, industry-sponsored PBL classes at the authors' university [2]. Since its creation, the classification has been applied and refined to additional engineering courses, team-based research and industry partnerships. This paper presents a version of the classification that was used recently in a graduate engineering course on innovation and emerging technologies.

It should be noted that the classification developed in this article is only one of many possible classifications utilizing a standard taxonomic methodology. It is a tool that creates new dialogue and does not aim to be exclusive, penultimate or authoritative.

PBL AS SKILLS IN CONTEXT

The creation of most PBL classes is built around the delivery of a real-world learning experience to the students. The performance requirements of the tasks in the class are meant to replicate those of the real world. Therefore, a primary goal for educators is to create a situation where the skills (know-how) and knowledge (know-what) that is experienced in the class is analogous to that learned in the real world. The advantage of a classroom environment is that learners can be provided with additional support, time for reflection, lessons, or feedback that may not be possible in the real world. This time for planned reflection of the experience is one of the key elements responsible for the success of PBL.

As mentioned above, the experience can be

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viewed from the perspective of contextual skills and content knowledge. Content knowledge, or know-what, is integrated into the learning experience through lectures, books, manuals, or other hard materials. The complement to this explicit knowledge is know-how, or implicit knowledge. This implicit knowledge is captured in skills that students are expected to already 'know' or to learn in the class.

Therefore, a real-world problem and a PBL problem can each be described by a content topic and the contextual skills are learned and applied. A result of this comparison is that the measurement of skills performance in the PBL setting should be equivalent to skills performance in the real-world problem. To address this comparison, the authors looked to existing research in human performance evaluation in operations research. Extensive work has been developed around context and skills using taxonomic classifications. Across this work, the objective is to capture the full extent of human skills, in context, that are required to measure performance gains or to provide comparison.

TAXONOMIC METHODS AND PBL

The application of taxonomic classifications is not new to learning research. Bloom's taxonomy is a classic in the education space and has ongoing value for some aspects of PBL [3]. But taxonomic classification that focuses on the learning of skills within a specific context has not been applied to problems in PBL. The authors found no taxonomic classifications in usage or in development by the PBL community. With the increasing adoption of PBL programs, the authors set out to develop a taxonomy, classification and tool to advance communications among educators. A secondary set of goals was the creation of a classification and tool that could be used by teams, students and industry practitioners working in the PBL space. The tool was therefore built to support learning paths, the creation of common language and trust in teams, and the development and sharing of career paths.

The taxonomic method presented in this paper was chosen based on its previous application to the classification of multiple aspects of human abilities. The basis for this research is the F-JAS system, available from the Management Research Institute, which was developed as a comprehensive system for human physical task analysis in the 1950s [4]. This work was extended by one of the authors in the mid-1990s for comparison of task performance in real and virtual environments, focusing on military simulation systems [5]. This previous work focused on the transfer of the method to a new area of application. It re-applied the methodology at a fundamental level in order to remove assumptions in the original taxonomic classification that, while not incorrect, were no longer valid in the new area. This previous research helped to speed the development of the skills taxonomy and classification system in the PBL area.

ENGINEERING LEARNING SKILLS AND CONTEXTS

The research program that supported the developed of the taxonomic classification tool was performed in an ongoing graduate PBL class at the authors' university. This three-quarter, industry-sponsored class is designed around a team-based learning experience for mechanical engineering graduate students intent on learning more about product development, team interaction and prototype creation. All of the teams work on projects that are proposed and funded by a collection of international companies. The authors' strong connection to the course is based on the participation by all three in various roles: two of the authors participated as learners and secondary educators while the third is actually the creator of the course and has been the course's primary educator.

The original goal of the research in the course was to develop a set of tools to better measure and correlate the learning and experience of the teams with their real-world contemporaries. While acknowledging that a PBL class is not intended to mirror the experience of a real-world project, the authors wanted to better communicate the similarities and values of the course to other engineering educators, PBL designers and industry affiliates. The research began by documenting and noting design team interactions in the capture and transfer of process knowledge, optimization of learning, creation of artifacts, and management of risk.

One of the recurring observations was the importance of communication between team members, between team members and industry, and with members of the extended teaching team. One of the first areas where communication was breaking down was in the discussion of an individual's background as it related to skills and knowledge: personal history, coursework, real-world experience, or other relevant experiences. This breakdown limited the creation of trust early in the formation of each team. It limited the teams' ability to communicate their collective skills and knowledge to the industry sponsors, and it limited their ability to communicate to the faculty, outside coaches and student mentors.

In order to address this issue, a simple list of skills and knowledge that each student probably brought to the class was defined. A second list of skills and knowledge relevant to success in the class—from a team, project and prototype perspective—was defined. A comparison of these two lists was to be expected. In our observation of this PBL experience, two areas of knowledge work in concert to enable the educational experience of

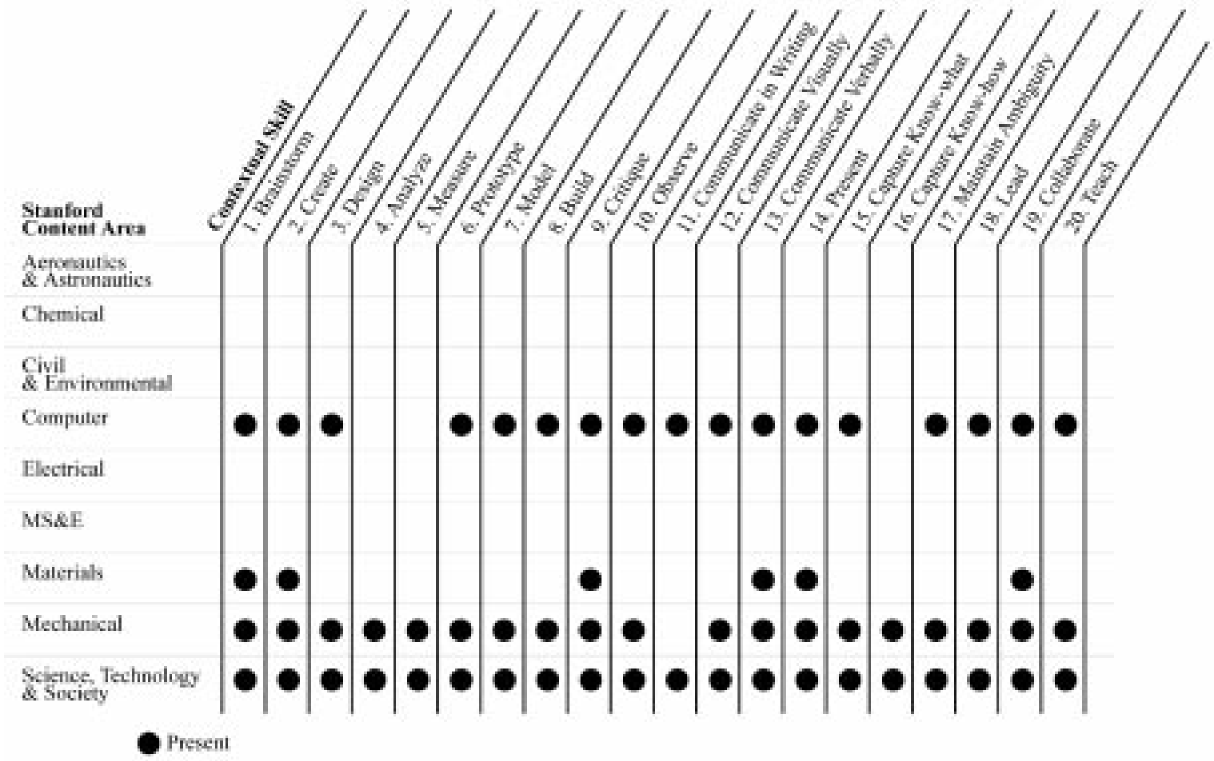

Fig. 1. An example of the presentation of absence/presence scoring.

the learner. The first knowledge area is classically thought of as the skill being taught or learned. These tasks are often discussed as 'learning goals' for a class: brainstorming, analysis, design, entrepreneurship, writing, etc. The second knowledge area that is critical to understanding the learner's experience is the context, such as the problem type or problem area. Common context areas from an academic viewpoint are mechanics, thermodynamics, and design engineering. Taking a more problem-focused view, context can also be defined as consumer product development, engine design or computer systems architecture.

The combined lists that had been created presented a course based on a mixture of skills and contexts. A sample of the contexts that were offered to the students, based on the specific needs of the industry sponsors during one year of the course, ranged from medical devices to automotive manufacturing to airline furniture. Each of these areas provides and requires a different context for the students. The context of the problems undertaken defined: the languages that the students needed to learn and use; the knowledge that needed to be acquired and integrated to complete the project; the sources and types of knowledge; the time-frame that the businesses and students must operate within based on the market the product exists in; and the way in which the final knowledge must be delivered to the client or customer.

When reviewing the list of skills with the revised context list for the course, a number of skills were added that extended beyond those of 'traditional' engineering, such as storytelling, visual communication and leadership. We then defined each of the skills using a simple definition and examples. Drawing from the taxonomic methodology mentioned previously, each skill was further developed within a seven-point anchored scale, with anchors or examples of the skill at the limits of the scale. The skills were tested through multiple iterations with faculty and other researchers, although no formal measurement of separation or completeness was done.

The refined skills list was then used to define multiple matrices to test possible usage models. In each matrix, a set of skills was defined across the top, with the left column comprising the content area or contexts within which the skills were considered. Figs 1 and 2 both show a skills matrix that was developed for team creation in a separate PBL course. Along the top are the skills that the students had probably learned, while the left-hand column shows the degree or engineering disciplines at the university. Referring again to the description of the skills, the matrices were presented along with the definitions for each skill. One example of the definition for 'writing' could be:

Writing is the ability to capture explicit knowledge, information and data in a written form, using the language of the community for which the knowledge is intended.

The definition initially allowed for analysis of the skills using an absence/presence evaluation and

Stanford Content Area / Contextual Skill	1. Brainstorm	2. Create	3. Design	4. Analyze	5. Measure	6. Prototype	7. Model	8.Build	9. Critique	10. Observe	11. Communicate in Writing	12. Communicate Visually	13. Communicate Verbally	14. Present	15. Capture Know-what	16. capture Know-how	17. Maintain ambiguity	18. Lead	19. Collaborate	20. Teach
Aeronautics & Astronautics	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Chemical	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Civil & Environmental	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Computer	5	5	3	1	1	5	6	4	3	5	2	2	4	3	2	1	3	3	5	2
Electrical	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MS&E	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Materials	3	2	1	1	1	1	1	1	2	1	1	1	3	2	1	1	1	1	2	1
Mechanical	4	4	3	2	2	3	4	3	5	2	1	2	5	4	2	2	4	2	6	2
Science, Technology & Society	6	6	4	4	2	4	4	3	7	5	5	6	7	7	4	2	4	4	6	2

1, 2, 3, 4, 5, 6, or 7 Scaled Score

Fig. 2. A scored matrix for absence/presence scoring.

reporting scheme. In this absence/presence evaluation, students went through each cell of the matrix to decide whether they possessed the skill within the appropriate context. If they felt that they possessed the skill, then they simply entered a check in the box. An example of the presentation of absence/presence scoring by a student in this class is presented in Fig. 1.

The students were then asked to revisit the matrix and to provide a score for each of the skills/contexts that they had marked as being part of their experience. A scored matrix for the same student can be seen in Fig. 2. The scoring used the seven-point anchored scales discussed previously.

The class was reconvened after each student had completed the scored matrix. The discussions began with one of the students discussing the groupings of contextual skills that they scored highly in, moving to a class-provoked presentation of examples by that student. The remainder of the class followed this pattern, with more cross-comparison between student examples occurring as the class progressed. At the end of the class, the authors had a better sense of the skills that each student perceived that he brought to the class, additional skills that the team had pointed out in each other, what the team thought it could accomplish and where it might need help, and a common language for discussing the learning goals that each student had for the class. The exercise was also performed by the class leaders and shared with the team, providing additional areas for trust creation in the class setting.

The matrices used in this class are being revised and are scheduled for inclusion in team-building activities in an upcoming engineering class on creativity and innovation. The plan is to introduce a refined version of the matrix tool, using a longer list of contexts and skills, in the next offering of the industry-sponsored PBL course.

Further uses of the matrix tool are planned for testing during the PBL course, such as the comparison of:

- skills learned versus skills required for industry projects and jobs;
- skills learned over time, such as through a student's educational experience (this will be explored initially as a before and after in the course); and
- the creation of teams around the skills required for the problem context (better team creation may be possible by comparing a context skill matrix with a proposed team's aggregated matrix).

CONCLUSIONS

The initial focus of this research was to understand interaction and communication issues that existed in an existing engineering PBL program. This paper presents an assessment tool that has been developed to enable and enhance communication among learners, educators, researchers, or other practitioners. The tool has been used to enhance student trust-building and initial communication, with plans to address a question facing PBL educators and researchers today: 'what skills are being learned and in what areas?' From initial usage, a user of a skills matrix can make reasonably accurate predictions about what skills a learner has developed in context and where this can be applied to real-world problems.

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Larry Leifer is Professor of Mechanical Engineering Design and founding Director of the Stanford Center for Design Research (1982 to the present). He has published in the areas of diagnostic electro-physiology, functional assessment of voluntary movement, human operator information processing, rehabilitation robotics, design team protocol analysis, design knowledge management, and concurrent engineering. Prior to joining Stanford University, Professor Leifer worked for Hewlett-Packard, General Motors, NASA Ames Research Center, the MIT Man-Vehicle Laboratory, and the Swiss Federal Institute of Technology in Zurich, Switzerland, where he taught Biomedical Systems Analysis. A member of the Stanford faculty since 1976, he has taught product design, created the smart product design (mechatronics) curriculum at Stanford, and, most recently, teaches a graduate course in 'Team-Based Design Innovation with Corporate Partners'. He was founding Director of the Stanford-VA Rehabilitation Research and Development Center (1978–1989) and, more recently, founding Director of the Stanford University Learning Lab (1997–2001). With the intention of disseminating orphaned medical device technology, he co-founded Lingraphicare America (1989) and Independence Works (1992).

John Feland is currently a Ph.D. candidate in the Design Division of the Mechanical Engineering Department of Stanford University. A former IDEO designer, John was also an officer in the Air Force where he assisted in the development of next generation missle warning satellites. His last assignment was as an Assistant Professor at the Air Force Academy. His current research is developing methods to support cross discipline product development and Innovation Opportunity Assessment based on field research in innovative companies, empirical studies of successful products, and his experience as a designer.

William Cockayne is Research Manager for Create Switzerland and a principal at Change Research. He brings over 10 years of industry leadership, working with forward-looking companies such as the Institute for the Future, Herman Miller, DaimlerBenz Research, and Apple Computer. He was formerly Director of Kodak's Innovation Incubator, where he identified misfit technologies for seeding startups. He has written multiple academic publications, including *Mobile Agents*, a book about Internet software agents. He is currently a doctoral candidate in mechanical engineering at Stanford University, where he is focusing on informal networks of innovation.