In this article we advance a methodology for capturing and tracing the development of novice engineering students engaged in a year long creative design and implementation project. The Setback Episode Based Analysis (SEBA) methodology allows researchers to identify relevant setback data from an e-portfolio environment (V-dot diagram), and then to sort these episodes into a set of categories that can illuminate the experiences of novice teams, revealing the complicated situations encountered as they faced roadblocks from creative product idea generation to its design and implementation. The SEBA methodology is especially useful for researchers interested in exploring subtle nuances among different groups when carrying out their tasks and producing their creative products. In addition to setting the context and providing a theoretical rationale for the SEBA methodology, this discussion includes a detailed description of the methodology along with its application to data sets. Following the five examples presented, we close with a discussion of the scope and limitations of this methodology, touching on issues of the breadth and depth, and the ideal vs. the reality of implementing creative products.
INTRODUCTION

Recognizing the importance of developing design skills to engineering students, a number of undergraduate programs have begun to incorporate innovative design experiences and assessment into junior and senior level courses. Portfolio assessment is one of the promising assessment tools for design and project-oriented learning. However, in spite of so many advantages, portfolio assessment presents significant logistical problems in regards to sampling, storage, and the development of assessment rubrics (Middle States Commission on Higher Education, 2002 [1]). The current development of various types of rubrics includes simple checklists, simple rating scales, detailed rating scales, and holistic rating scales. Of these, detailed rating scales are highly effective for describing explicitly what constitutes deficient, adequate, or exemplary performance within each of the criteria.

However, when most of the learners are novices, the rubric scores reveal little information and provide no evidence as to why do they not learn. The “why” of student learning is particularly important when students fail to learn, because one of the primary goals of assessment is to make future learning experiences more effective.

In this study, using e-portfolio assessment via an interface called V-dot diagram to scaffold learning-to-design activities, the authors encountered problems with how to evaluate novice teams on their creative design and implementation. Instead of using existing general rubrics with limited information on how these junior and senior engineering students were doing and what particular difficulties each team met, we propose a Setback Episode Based Analysis (SEBA) methodology to identify roadblocks to creative design experienced by these novices. The findings reflect learning in context and the complex thinking skills that are more involved than those found in problem-solving activities.

1. THEORETICAL BACKGROUND

The SEBA methodology was developed with two theoretical concerns. One is to consider design and implementation as a kind of reflective practice on the analytical knowledge learnt. The other is to emphasize the usefulness of visualizing the interweaving of knowledge and methodology, and the evolution of the originality value throughout the creative design and implementation process.

1.1 Learning to Design as Reflective Practice

In spite of the theoretical appeal of situated cognition (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Roschelle & Clancey, 1992; Roth & Bowen, 1995 [2-5]), there have been few attempts to develop methodologies for making sense of how learner understanding and difficulties are generated and how they are grounded in their particular context. In fact, research on design engineering tends to look at the outcomes of learning, not the process of learning; it tends to develop rubrics for achievements and not to explore the roadblocks that lead to failure.

From the perspective of Schon’s reflective designing (Schon, 1983 [6]):
“The designer’s making process is complex. He works in particular situations, uses particular materials, and employs a distinctive medium and language. There are more variables -- kind of possible moves, norms, and interrelationships of these -- than can be represented in a finite model. Because of this complexity, the designer’s moves tend to produce consequences other than those intended. When this happens, the designer may take account of the unintended changes he has made in the situation by forming new appreciations and understandings and by making new moves. He shapes the situation, in accordance with his initial appreciation of it, the situation “talks back”, and he responds to the situation’s back-talk.”

We found Schon’s excerpt above to fit in well with our exploration of the novice designer’s setback experience. In Schon’s description, “In a good process of design, this conversation with the situation is reflective. In answer to the situation’s back-talk, the designer reflects-in-action on the construction of the problem, the strategies of action, or the model of the phenomena, which have been implicit in his moves.” On the contrary, (McCracken 1997 [7]) depicted the learning process of these novice designers as “design luck” and maintained that they have preconceived notions of design, are focused upon ideation, that they quickly drop into dealing with minutiae without problem decomposition, and that they focus upon single point solutions and keep coming up with single point answers until they get lucky.

In comparing the expert with the novice in the field of design, we found that it is the notion of “reflective practice” that makes them perform differently. The novice seems to have little experience and awareness of how to have reflective conversations about the situation, therefore they tend to avoid facing the problems rather than to apply reflections-in-action to them. The SEBA methodology, based on the concept of reflection, is proposed to examine instances of setbacks and the pattern of failures in novices’ portfolios. Relying solely upon rubric scores tends to bury these crucial nuggets of insight into why these novices cannot develop into expert designers.

1.2 Vee-dot Diagram as a Visualized Scaffolding Model

The epistemological Vee diagram was developed by Gowin (1981 [8]) and made a substantial contribution to the assessment of science understanding (Trowbridge & Wandersee, 1998 [9]). His view is that creating new knowledge in the natural sciences involves a critical interplay between conceptual and methodological issues. He refers to the sides of the V as “thinking” and “doing.” The focus question in the top is the beginning point of any scientific investigation and typically addresses issues of what, when, how, or why. Choosing this question is almost certainly the most important decision a scientist makes. The bottom of the V diagram represents events / objects.

The creativity realization process resembles the science learning process. Prior knowledge and daily experiences interact to promote the evolution of an original idea for the realization of a creative product. The V diagram is modified into the V-dot diagram (Chen, Hsiau, Wu, & Yeh, 2004 [10]) emphasizing the project evolution around that original creative idea, the principles of creativity, the goals for innovation, and the perceived selling points of the product represented by the dot on top of the V-dot diagram, as shown in Figure 1.
[Selection of Project Team] Team Members

Knowledge
- Living experience
- Theoretical advancement: theory / hypothesis / principle
- Material properties
- Manufacturing know-how
- Information / data sheet links
- Budget estimate and control

A Priori and New Acquisition
- Difficulties and resolution
- Team work strategy and decision making

Reflections
- Self evaluation (product, team work, team members)
- Memorandum and advices to future junior course mates

DOCUMENTATION
- V-dot Diagram Interface
- Survival Guide

IDEA
- Principles of creativity
- Creative selling points

PROJECT
- Our growth
- Implementation

Methodology
- Brainstorming
- Creative idea generation / Evaluation / Topic selection
- Planning / Gantt Chart / Task assignment

Reflection
- Marketing
- Patent research
- Related product disassembly for reverse engineering
- Sketch drawing / Layout design / Prototyping
- Application of theories
- Expert consultation (teacher, technical master, shop keeper)

ACTION
- Design
- Material and component acquisition
- Product manufacturing and user’s manual

MANUFACTURING
- Product testing

INVESTIGATION
- Marketing
- Patent research
- Related product disassembly for reverse engineering
- Sketch drawing / Layout design / Prototyping
- Application of theories
- Expert consultation (teacher, technical master, shop keeper)

Exploration
- Planning / Gantt Chart / Task assignment

Check list
- Implementation
- Comromise

Comprehension
- Our growth
- Implementation

PROJECT
- V-dot Diagram Interface
- Survival Guide

FIGURE 1
THE CATEGORY ITEMS IN THE V-DOT DIAGRAM
As the creative idea gets pushed through design and implementation towards realization of a final product at the bottom of the V-dot, the implementation action (the methodology side) is driven first by a priori knowledge (knowledge side). This process can be represented by an arrow from left to right. As the result of methodological procedures, new experiences are gained and new understanding is recognized and accumulated, which is then represented by an arrow from right to left. Going back and forth, the original creative idea is altered, modified, and brought towards convergence and a focused reality at the bottom tip of the V. Throughout the process, the knowledge that is recognized and constructed is deposited into the knowledge database on the left as the common wealth of the group. Using the V-dot diagram as the framework for collecting and organizing the portfolio of a team’s progress, we were able not only to capture the phenomenological activities but also the causality sequences and the element of conceptual progression.

All tasks for the creative project design and implementation were collected and classified into twelve categories listed on the methodological side of the V-dot diagram, while the correlated thought process, comprehensions, reflections, and advices to potential attendees were collected and classified into ten categories as listed on the knowledge side of the V-dot diagram. The V-dot diagram was implemented as a web based e-portfolio or logs interface and students were required to document all their activities through this interface. The categories on the methodology side were listed in their natural canonical sequence to serve as a scaffolding model of an expert’s thought process. While there was no definite casual sequence for the categories on the knowledge side, the categories were listed in an order loosely related to the task categories on the methodology side.

2. THE SETBACK EPISODE BASED ANALYSIS METHODOLOGY

In advancing a methodology that is empirically grounded, we initially describe actual data collected as part of our previous research to further illuminate the process and the usefulness of our methodology. We provide examples and analysis that are rich enough to illuminate the process and the potential of this methodology for capturing reflection-in-action. We close with a discussion of the limitations of this methodology, touching on issues of the breadth and depth, the ideal vs. the reality of implementing creative products.

2.1 Data collection

The goal of data collection is to capture evidence of novice learning (or failing to learn) in a way that allows researchers to appreciate fully its complexity together with that of the difficulties the novices encountered, and to make that evidence accessible for further analysis. The major part of the data was collected through the log entries in V-dot diagram interface (described more fully below). It was introduced as an e-portfolio to students. As has been established, a well-designed portfolio will meet the teaching goals of engaging students in higher order cognitive activities, reflection, and creativity (Arter and Spandel 1992; Gardener 1992; Biggs 1998 [11-13]). At their best, portfolios can act as a silent mentor becoming an instrument of learning as well as a repository, thus students become a responsible partner in documenting and evaluating their own learning (Gardener 1992 [12]).
The original creative ideas are represented by the dot on top of the V shape. It will be taken through a sequence of knowledge driven methodological actions of creativity generation and through design and implementation stages in order to evolve into the final product at the bottom tip of the V. Each action will in turn produce experience and acquired knowledge to be documented on the knowledge side of the V, which in turn, inspires further actions and evolutions.

The team members are asked to document their log entries through the V-dot interface, each team maintaining one data set contributed by all its members. Every event to be documented is to be entered according to its nature — its knowledge category or methodological action (design and implementation) stage. The event nature is divided into 10 knowledge categories labeled along the left side of the V, and into 12 action stages labeled on the methodology side, to the right of the V.

The 10 conceptual items for entries along the left hand side of V-dot are:
1. Personal Living Experience
2. Theoretical Advancement : Theory / Hypothesis / Principle
3. Material Properties
4. Manufacturing Know-How
5. Information / Data Sheet Links
6. Budget Estimate and Control
7. Difficulties and Resolution
8. Team Work Strategies and Decision-Making
9. Self Evaluation
10. Memoranda and Advise to Future Junior Course Mates of the CED (Creative Engineering Design) course

The 12 methodological items to be entered along the right hand side of the V-dot are:
1. Brain Storming
2. Creative Idea Generation / Evaluation / Topic Selection
3. Planning / Gantt Chart / Task Assignment
4. Marketing
5. Patent Research
6. Related Product Disassembly For Reverse Engineering
7. Sketch Drawing / Layout Design / Prototyping
8. Application of Theories
9. Expert Consultation
10. Material and Component Acquisition
12. Product Testing

Eventually, these portfolios will be selected according to their relationship to setback events and will be identified into episodes, assigned attributes, and organized in profiles for group comparison. The ability to assign attributes is dependent upon the human observer’s familiarity with the context. As such, our data collection procedures involve researchers also engaged in direct face-to-face observation in the classroom. To supplement and triangulate interpretations, our team also collects field notes and student-constructed artifacts, and carries out interviews on the group.

2.2 Defining setback episodes
Operationally, identifying the raw data and categorizing it into meaningful units (Jordan & Henderson, 1995 [14]) is the first step in the creation of a profile on novice learning. The units are defined as a description of the process of struggling with difficulties. Given our emphasis on setbacks or roadblocks, we refer to these units as setback episodes (SEs). An SE is identified as an event occurrence that is judged to be a “concrete block happening” in the process of creative design and implementation. The repertoire of a SE may be a story or statement containing reflections, complaints, giving up, or, working out at last as documented in the log entries.

Each instance of an SE was identified as one of ten facets. Somewhat similar to the items in the V-dot diagram, the facets were: “Concept Formation”, “Material/Component”, “Analysis/Calculation”, “Spec Selection”, “Tolerance”, “Manufacturing”, “Fitting/Assembly”, “Testing/Verification”, “Budget”, and “Teamwork” (see also Table 5). Although student entries were located according to each item in the V-ee diagram, the contents of these entries in each item were mixed with various encounters and concerns, which conveyed richer meanings than the original item. In other words, it is not always possible to categorize SE as one single facet as there were mixed attributes embedded in these SEs. As such, our sorting procedures involved a “close reading” (Moss & Shank, 2002 [15]) technique. According to Barthes (1968 [16]), the texts manifest structures that are both denotative and connotative. In order to explore the underlying attributes of each SE, those authors who had majored in mechanical engineering employed “close reading” to judge professionally the facets that each of the SEs reflected. We found this to be the most challenging aspect of the data analysis.

Reconstruction of the time sequence of setback episodes was not easy. The documentation of events had been made by the students on the web through the category items (10 on the left and 12 on the right) labeled in the V-dot diagram. Therefore, one data entry might have been a story covering a sequence of actions spanning many different methodological stages and generating knowledge in many different categories. We had to rely upon the teachers and the teaching assistants who were aware of the team history to organize the sequence of recorded events and to supplement the record by providing missing links in order to trace the zigzag paths of episodes of engineering or educational significance.

However, the interview data of each group complemented each other in triangulation. The purpose of the interviews was, firstly, to supplement any deficiencies in the database and to verify the correctness of the researchers’ interpretation of events, causality sequences, and underlying reasoning, but also served to solicit students’ comments on the course and its classroom activities.

2.3 Visualizing the features of multiple facets of SEs

In visualizing the data (reflection-in-action), we found it useful to present the identified attributes of each SE in each group with bars. Operationally, this process begins by developing graphs in which the Y-axis represents the ten facets, and the X-axis represents the SEs roughly arranged in time sequence (Figure 2). Examination of this figure reveals which group was occupied/ frustrated by or engaged in which facet and which SEs covered multiple facets. The goal of visualizing episodes was to generate a description that can scaffold the researcher’s interpretation and presentation of the novice group’s roadblocks.
Once a representation of the group profile of setbacks has been generated, the researchers can build a rich interpretation of the differences among groups. For example, which group demonstrates a breadth/depth of exploration, and a recognition of the complexity of the problem encountered with creative project design and implementation. When possible, member checks with the original groups were also performed to further validate interpretations.

In the above discussion, we described the process of constructing a profile of SEs. The process from the analysis of portfolios through the interview involves the following steps:
1. Collection of the data through portfolio in the V-dot diagram interface;
2. Identifying setback episodes, the unit of analysis that we have described as SEs;
3. Sorting each SE into facets (categories);
4. Developing a visual representation of the whole group’s SEs in a chronological sequence;
5. Re-examining the profile and the interview data to build an interpretation of each group’s learning trajectory;
6. Comparing the profiles of different groups in order to place the novices’ efforts or roadblocks in the process of creative project design and implementation.
7. Looking for further interpretations of highly correlated SE sequences.

3. INSTANTIATIONS

To illuminate the use of the SEBA methodology in the portfolio assessment of novice learning through designing, we describe the particular research context and how we have used SEBA to trace the development of SEs in each group.

3.1 Research context

The subjects.

The research data were collected from all students taking a project-oriented course “Open Ended Creative Mechanical Engineering Design (CED)” offered to junior and senior engineering students all of whom were majoring in mechanical engineering. They were mostly in their junior year with some in their senior year. Most of them did not have any design and implementation experience at all. They are therefore referred to as “novices” in this field.

The course.

The CED course is two semesters long with most of the activities being run by team of 4-5 people. In the first semester, concepts of creativity and design are introduced. Topics covered are the engineering design process, teamwork, the principles of creative thinking, creativity contests, the generation of project topics, and the plan for conducting projects. In the second semester, the course focuses on carrying out team projects and going through the process of creative product design and implementation. The process includes marketing surveys, data collection, product design, manufacturing, testing, and a final report. The project plan and the log entries of each team were documented on the web through its member accounts on the V-dot diagram interface which provided a visual realization of the framework of creative product design in order to guide students through creative idea generation, design and implementation.
By documenting their activities, thoughts and reflections through the V-dot diagram interface, team members reveal these efforts, the knowledge and experiences gained, and create a picture of the formation and evolution of the final product. Students were required to document all their activities and thoughts on the web as part of their grade.

There were regular face-to-face checkpoint dates set for the teams to present their progress and to receive inquiry and comments from everyone. This was conceived as a scaffolding and feedback activity created so that every team had to think through their ideas and concepts and be responsible for their implementation. In this course, students learn to apply their knowledge in an integrated manner and to experience hands-on design and implementation so as to enhance their flexibility, technological creativity and realization capability.

**Case selection.**

There were, in total, more than 20 teams in the academic years 2001 and 2002 and the amount of documentation generated by each team ranged between ten and twenty thousand Chinese characters -- an enormous quantity to analyze. Based on one of the V-dot diagram assessment tools, the Gap Value, five teams were selected (Table 1) for this study.

<table>
<thead>
<tr>
<th>Group</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of the Product</td>
<td>baggage going upstairs</td>
<td>multi-directional monitor / speaker stand</td>
<td>remote bicycle lock</td>
<td>big tummy garbage tank</td>
<td>Solar power vented backpack</td>
</tr>
<tr>
<td>Creative idea</td>
<td>Slide along the stair railing</td>
<td>Adjustable</td>
<td>To be used on bicycle</td>
<td>Automatic garbage compression</td>
<td>Blowing air on the back for ventilation</td>
</tr>
<tr>
<td>Critical Issues &amp; Turning Points</td>
<td>Moving mechanism</td>
<td>Adjustable mechanism</td>
<td>Electronic remote control</td>
<td>Moving mechanism</td>
<td>Support frame</td>
</tr>
<tr>
<td>Mechanical / Mechatronic</td>
<td>Mechanical</td>
<td>Mechanical</td>
<td>Mechatronic</td>
<td>Mechanical</td>
<td>Mechatronic</td>
</tr>
</tbody>
</table>

**Table 1**

**The Five Selected Cases**

The Gap Value was designed to assess the difference between the original idea conceived by the team and the final product generated. The notion of The Gap Value was put into operation in five dimensions (Table 2) and the team performance could be scored in each dimension. The score for each dimension ranged from 0 if no gap was found at all to 2 if the gap was obvious. Thus, the total score of all five dimensions could range in theory from 0 to 10. The average score of the five selected groups was 3. Actually only one case scored 2, the remaining cases were all 3 (see also Table 4). We purposely selected these groups because their performance was roughly equal as assessed by using rubrics. The SEBA methodology was intended to be useful in revealing subtle nuances among groups of similar performance.
<table>
<thead>
<tr>
<th>The Aspect of Creativity Fall Off</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some original functionalities were missing.</td>
<td>The originally proclaimed functionality was absent from the final product.</td>
</tr>
<tr>
<td>The present functionality was less than expected.</td>
<td>The originally proclaimed functionality did not turn out as eye catching as was expected.</td>
</tr>
<tr>
<td>Just a mock up without physical effects or load baring capacity.</td>
<td>Due to compromises and evasion, the final product might take shape but have no function.</td>
</tr>
<tr>
<td>The product was unstable or unreliable.</td>
<td>The functionality of the product was unstable to the extent that it could fail during the demo.</td>
</tr>
<tr>
<td>The difference between the product and the design drawing.</td>
<td>Due to poor design practice, the design, as illustrated, needed modification to be built properly.</td>
</tr>
</tbody>
</table>

**TABLE 2**
**GAP VALUE: DIMENSIONS OF THE GAP BETWEEN THE ORIGINAL DESIGN AND THE FINAL PRODUCT**

### 3.2 Analyzing the data

In the portfolio of each team, we reminded students during semesters to keep documents as detailed as possible. For example, for each event track, they were asked “what was the original acknowledgement,” “what was the a posteriori recognition,” “After the a posteriori recognition, what was the follow up actions taken,” and “The reasons for taking those follow up actions.” Therefore the statement would report not only the components involved in that particular setback but also a sense of reflection on the problem. In addition, rather than arbitrarily segmenting data into very clear-cut SEs, we treated the situation surrounding each setback as the actual unit of analysis. In this way, we were not relying entirely upon the specific details of “events” but were able to achieve a general picture of how many critical periods of setbacks the group encountered. Those are the concerns of the present study. Excerpts from SEs are below:

“The gap between spring and compression bar was too small that the compression plate might tilt and jam at various garbage height. Enlarging the gap turned it smooth.”

“Affixing the supporting frame to the baggage we needed to mark the correct location to drill screw holes, since the holes on the baggage located by metrology usual do not match that of the holes on acrylic plate of the supporting frame. We needed to enlarge the holes to allow fastening screws to go through to hold frame and baggage together.”

“We realized that, since we over idealized about the implementation, we overlooked practical problems on manufacturing, and budget. We did start to leave time for every team member to raise their concerns and we went through the discussion for solutions one by one. This way we all developed common understanding on the new design so that we worked together for higher design efficiency instead of personal show of the few.”
“This experience told us that “the best plan still needs adjustments facing up realities”, “even a flash of idea should be documented and followed up with actions, it could just be a better selection.” Of course, we were not barking up every tree. We did carry out serious analysis and reviews before taking on any turn. However, some materials were hard to acquire ...”

Sixty-six SEs were identified in the five cases. Using “close reading” by two engineering experts, each SE was identified according to which facet(s) this SE involved. (examples were in Table 3). In other words, this break down reveals the attributes of each SE occurring in each group.

<table>
<thead>
<tr>
<th>Corresponding Design Stages/ Facets</th>
<th>Setback Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Material” “Budget” “Concept Formulation”</td>
<td>We designed (figured out) a set of modular supporting frame to affix rollers onto the side all of the baggage while clinging onto the railing of any regular stair. Originally we were to use a clamp. We abandoned the idea because we could not find a suitable one on the market and, moreover, we could not find appropriate material to make for ourselves. Making the parts ourselves would mean expensive new mold or die.</td>
</tr>
<tr>
<td>“Testing”, “Analysis”, “Concept Formation” “Material/Component”, “Manufacturing”</td>
<td>Increasing the adaptability to the stair, we added a pair of roller on the side. We tried to adjust the location of the rollers, however, it was not easy to keep the lateral balance and we decided to add a horizontal iron bar at the end of the supporting frame.</td>
</tr>
</tbody>
</table>

**TABLE 3**  
EXAMPLES OF THE CORRESPONDING DESIGN STAGES/ FACETS OF SEs

The resulting frequencies of the total number of SEs in each group, and their design and implementation facets are listed in table 4.

<table>
<thead>
<tr>
<th>Group</th>
<th>The Gap Value</th>
<th>Number of SEs</th>
<th>Count of facets covered by SEs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baggage going upstairs</td>
<td>3</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Multi-direction monitor / speaker stand</td>
<td>3</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Remote bicycle lock</td>
<td>2</td>
<td>13</td>
<td>23</td>
</tr>
<tr>
<td>Big tummy garbage tank</td>
<td>3</td>
<td>16</td>
<td>39</td>
</tr>
<tr>
<td>Solar power vented backpack</td>
<td>3</td>
<td>19</td>
<td>47</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>66</td>
<td>139</td>
</tr>
</tbody>
</table>

**TABLE 4**  
THE FREQUENCIES OF SETBACK EPISODES AND THEIR CORRESPONDING FACETS IN EACH GROUP

3.3 Interpreting the data
These figures showed that a large number of SEs were involved in more than one facet of the creative design and implementation stages. How widely these SEs are spread may be important for a deeper understanding of these groups. The SEBA methodology produces such inscriptions for the researchers that can scaffold the interpretation as well as the presentation of the data.

**FIGURE 2**
The facet map of the setback episodes
WHERE, THE TEN MICROSCOPIC FACETS WERE LABELED AS A= "CONCEPT FORMATION"; B= "MATERIAL/ COMPONENT"; C="ANALYSIS/CALCULATION";
D= "SPEC SELECTION"; E="TOLERANCE", F="MANUFACTURING";
G="FITTING/ASSEMBLY"; H="TESTING/VERIFICATION"; I="BUDGET"; AND J=
"TEAMWORK";

WHILE, THEY WERE DEVIDED INTO FOUR MACROSCOPIC ASPECTS FROM THE
TOP TO BOTTOM: CONCEPTUAL DESIGN; LAYOUT; IMPLEMENTATION
(MANUFACTURING, ASSEMBLY, CALIBRATION, TESTING); AND
ADMINISTRATION / COORDINATION.

On the one hand, by investigating each figure horizontally, we can learn how each
facet was covered and how important the facets of each group were in terms of the SEs.
The 10 facets were further grouped into four large aspects (see Table 5) for the sake of a
macro-view and were distinguished from one another by a gray line. In this way, comparing
groups becomes a multi-level analysis process. For example, case 4 and 5 emphasize heavily the “Layout” Aspect, while cases 2 and 3 emphasize the “Conceptual Design” Aspect.

On the other hand, looking at each figure vertically, one can visualize the complexity
of the attributes of SEs. Only 1/3 of SEs occurred with only a single facet, the remainder
having at least double blocks in the SEs. It seemed that cases 4 and 5 had fewer single
blocks than did cases 1, 2 and 3. The complexity of the SEs in each group was easily
compared. In terms of the breadth and the depth of facets, the five figures revealed that
case 3 covered the four Aspects most evenly, while case 5 certainly explored their
product most deeply. Looking into the multiple attributes of setback episodes, we
discovered several highly correlated facets in figure 2 that deserve more attention. They
may reveal further ramifications of the difficulties encountered by novices in the
realization of creative products. Based on these highly correlated / linked setback episode
sequences, our interpretations were:

1. (“testing/verification”, “analysis/calculation”, “spec selection”)
   Our junior and senior year students were still novices as regards practical design
   and implementation experience. They were not familiar with the professional
design process. They simply did not believe in the process of doing analysis and
calculation first before material selection, manufacturing, and assembly. They
would rather make their purchases and do their construction by intuition. Setbacks
were therefore inevitable. When there were many parameters involving the
properties of materials interacting to influence the performance and functionality of
the product, how to twig intuitively for an acceptable solution was not at all
obvious. The novices were forced to go back and do analysis and calculation
rationally like professionals.

2. (“material/component”, “concept formation”)
   Students were also novices to market availability and they did not get much of a
sense of it by referring to product catalogs and product data sheets. Many teams
mentioned that treks through large sale warehouses and hardware stores were their
most inspirational experiences.

3. (“material/component”, “analysis/calculation”, “spec selection”)
   This is a compound of sequence patterns 1 and 2, which revealed further insights of
the novices. In addition to market availability, they avoided a quantitative analysis
of their conceptual design. Moreover, most of the students could not do the
calculation on admissible sets that was required to define an acceptable range of
material or component properties. They were also unable to do variational analysis to prioritize selection criteria. Therefore, they ended up with very narrow target of selection and no alternative plans.

Finally, the overall picture of SEs in the five groups is summarized in Table 5 below. The most difficult facets to them were Spec Selection, Material / Component, Manufacturing, and Analysis / Calculation. These facets supported our interpretation of their beginning strategy as “make purchase and put together by intuition.” When they “were forced back to do analysis and calculation,” they were not used to “referring to product catalogs and product data sheets,” and were described as “could not do calculation on admissible sets to define an acceptable range of the material or component properties.” Finally, the conclusion that “they ended up with very narrow target of selection and no alternative plans” can be seen in novice group typical trajectories.

<table>
<thead>
<tr>
<th>The macro-view</th>
<th>The microscopic view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four Aspects</td>
<td>%</td>
</tr>
<tr>
<td>Conceptual design</td>
<td>29</td>
</tr>
<tr>
<td>Concept Formation</td>
<td>17</td>
</tr>
<tr>
<td>Material / Component</td>
<td>23</td>
</tr>
<tr>
<td>Layout</td>
<td>37</td>
</tr>
<tr>
<td>Analysis / Calculation</td>
<td>21</td>
</tr>
<tr>
<td>Spec Selection</td>
<td>25</td>
</tr>
<tr>
<td>Tolerance</td>
<td>6</td>
</tr>
<tr>
<td>Implementation (manufacturing, assembly, calibration, testing)</td>
<td>27</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>22</td>
</tr>
<tr>
<td>Fitting / Assembly</td>
<td>7</td>
</tr>
<tr>
<td>Testing / Verification</td>
<td>8</td>
</tr>
<tr>
<td>Administration / Coordination</td>
<td>7</td>
</tr>
<tr>
<td>Budget</td>
<td>8</td>
</tr>
<tr>
<td>Team work</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

TABLE 5
**DISTRIBUTION OF SETBACK EPISODES COUNT BY FIVE GROUPS IN TOTAL**

4. **DISCUSSION**

The setback episode based analysis started by generating basic quantitative data to reveal the profile of novice groups’ efforts from the portfolio. This methodology then visualized the features of multiple facets of SEs. We compared the differences between the groups and found much richer meanings that the traditional combination of portfolio and rubrics could hardly do. In our experience, the SEBA methodology was particularly beneficial for assessing novices in creative design and implementation for the following two reasons.

4.1 Novices were weak in their abilities to decompose problems systematically and therefore their logs clearly reflected that frustration.
Though taught the professional and logical design procedure, it is almost impossible to find an undergraduate student who would follow it through the iterative breadth to depth development process for realizing a creative product. Hence their portfolios were packed with setbacks, post-setback turning points, compromises, abandonment, and restarts from scratch. They jumped and switched seemingly randomly among design stages. The final products were the results of intuitive trial and error and were usually major retreats from their original creative ambitions.

Encountering obstacles, the novice tends to compromise or side step the issue instead of researching and conquering like an expert. There appeared an unusual number of loop back iterations in the novice’s records, which obscured the design logic. For example, novices rarely discussed or calculated the specifications of materials and components before their acquisition. Materials and components were most often happened upon randomly and selected by intuition as novices were wandering through warehouse stores, hardware markets, and large sale markets. As a result, originality suffered and product realization often changed direction as influenced by the availability of materials and components.

4.2 Novices tend to struggle with difficulties specific to their own products and therefore applying standardized rubrics to assess them might reveal little useful information.

The log entries did seem to reveal the dimensions and the depth of group efforts. Each group encountered different difficulties with each setback episode, turning point, or compromise. Their reaction and the extent of documentation reflected the dimensions, the aspects, and the depth and level of endeavor a group had put its effort into. Therefore, one can expect significant maturity from the group as far as its focus is concerned. For example, some groups put down significant records on the experiences of material and component selection, while some groups recorded detailed stories on manufacturing or performance testing. The SEBA approach attempts to reveal the characteristics of their individual portfolio records in order to show the facets in which they had gained significant progress regardless the quality of their final product.

4.3 Limitations

To encourage students to produce complete and detailed documentation on the generation of ideas, solution plans, and actions through the V-dot diagram web interface, we did calculate course grades based on the amount and significance of the records they logged. However, because computer and network were unavailable at specific times and places, combined with laziness and the tendency to make up log entries after the fact, log files were necessarily incomplete.

Teams differed also in their diligence and their thoroughness of documentation. The writing styles were inconsistent. Some teams may be thorough while others were relatively concise or even brief. Some teams might even have dedicated member responsible for documentation, who tended to beautify the records for extra credit rather than focus on technical significance and accuracy. In order words, the amount of data entered into the database did not necessarily reflect the extent and depth of the teamwork in a group and, therefore, the V-dot documentation might not have all the details. These phenomena rendered the importance of extra verification and clue tracking research effort beyond the examination of computer records. In order to recover the whole truth and to
verify the accuracy of interpretation, we had to sort through the data first to get prepared on the issues to be verified and supplemented during the follow up interviews.

5. CONCLUSIONS

Conventionally, “the design and implementation of creative products” is graded by creativity at every stage, the functionality, and the quality of the final product. Iterative efforts due to mistakes or procedural incompliance not only get no credit but also receive demerits. After all, novices are not fluent in, and frequently do not believe in nor do they follow formal design procedures. Therefore, conventional evaluation has rather poor discriminative power. However, even without enough prerequisite knowledge and experience, novices do have a survival instinct that leads them to negotiate a compromised path toward a final product. By changing the aspect of evaluation, we value how much the novices benefit from the process instead of how much had they accomplish and comply with guidelines. We developed the methodology of Setback Event Based Analysis (SEBA) to be encouraging and pro growth. We used the “The facet map of the setback episodes” and the resulting “highly linked setback event stage sequence pattern” to reveal the “versatility and functionality of the attempted product” and the “depth of exploration into the realization process.” We were therefore able to detect the level of the novices’ self-expectation and the extent of their commitment and efforts with an enhanced ability to discriminate.

ACKNOWLEDGEMENT

This research has been sponsored by the National Science Council of Taiwan, ROC under grant # NSC90-2511-S-008-002, NSC90-2511-S-008-003, NSC91-2522-S-008-003 and NSC92-2745-S-008-004.

We must acknowledge the support of our superiors, teachers, colleagues, students, and especially those graduate students who served as teaching assistants and had invested a part of their lives in our courses. “The key to obtain material results from funding is persistence and internalization” has gained our common recognition.

We owe our mechanical design capabilities to Professor Emeritus Chiang, Chiun-Hong of ME, National Taiwan University. The development of thinking models for various design phases was inspired under the persistent preaching of Professor Emeritus Wang, Nai-Chueh of the Institute of Optical Sciences on his logical design procedures of opto-mechatronic systems.

REFERENCES


**Fei-Ching Chen** received her Ed. D. from U of Massachusetts at Amherst in 1992. She has been an Associate Professor with the Institute of Learning and Instruction at National Central University since 1993. During 1995 to 2000, she served as the head of the Teacher Education Center responsible for its 1996 initiation. She applies social theory of learning in socio-cultural perspective to study the computer-supported collaborative learning communities and creativity.

**Tse-Liang Yeh** received the B.A. and a M.S. degree in Nuclear Engineering, a M.S. and the Ph.D. in Mechanical Engineering from UC Berkeley. After seven years of industrial experiences, he became an Associate Professor in design and
implementation of mechatronics and controls with the Dept of ME – Inst. Of Opto-Mechatronics Engineering, National Central U 1993 working on engineering education to enhance hands-on and design experiences.

**Shu-San Hsiau** received his M.S. and Ph.D. from California Institute of Technology in 1989 and 1993. Afterwards, he joined the Department of Mechanical Engineers in National Central University in Taiwan and became full Professor in 1999 working on granular flow, energy engineering, and engineering education enhancing creativity, design and implementation.

**Jiunn-Chi Wu** received his M.S. and PhD from Georgia Institute of Technology, Atlanta in 1985 and 1988. He is an Associate Professor in mechanical engineering with National Central University. His research is on the modelling of micro flows and microfluidic application. He got involved in the interdisciplinary engineering education research team since 1997.

**Nai-Chueh Wang** received the B.S. in electrical engineering from the Chung-Cheng Technological Institute, M.S. and Dr.E. in Nuclear Engineering from Tsing-Hua U in Taiwan and North Carolina State U. He retired as an Associate Professor in infrared and opto mechatronics design after teaching at the Institute of Optical Sciences, National Central University, 1987~2004.

**Shyi-Jeng Tsai** received his M.S. and Ph.D. in Mechanical Engineering from Technical University at Braunschweig, Germany in 1994 and 1997. He is an Assistant Professor in design and gear with the Dept of ME, National Central University, since 1999.