AC 2009-2084: RUBE GOLDBERGINEERING: LESSONS IN TEACHING ENGINEERING DESIGN TO FUTURE ENGINEERS

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Abstract

Hands-on learning experiences and interactive learning environments can be effective in teaching K-12 students. Design, in essence, is an interactive, hands-on experience. Engineering design can be taught in the classroom using innovative hands-on projects, such as designing and building serve to teach design, promote creativity, and provide opportunities for hands-on problem solving, in addition to giving students experience working in cooperative teams. In turn, these experiences could encourage students to consider future careers in engineering and science.

This paper explores findings from data collected during the authors’ recent experience teaching a group of fifteen 4th – 6th grade students enrolled in a 6-week Saturday talent development program to design and build Rube Goldberg machines. The purpose of the study was to investigate the effectiveness of teaching an engineering design to students enrolled in a talent development program, the use of teamwork and its influence in the design process, and how a design process aligns with the way kids approach design.

A scaffolded engineering design process was used to guide teams of 3-4 students through the project. Students took on predefined roles in order to promote teamwork. Most of the data collected were a regular part of the work subjects produced for the class, which included written descriptions of the designs, posters that include drawings of their designs, and photographs and video of the machines constructed. Additionally, the investigators maintained journals during the class, and evaluations were used to measure the students’ overall perceptions of the class. A grounded theory approach was used to determine both aspects of the course that worked well and areas for improvement, in addition to surprises encountered along the way. Using this approach allowed our conclusions to inductively emerge from the data.

In this paper, we will discuss the educational implications of the study. Results indicate that these students have difficulty working in teams, applying a design process, and demonstrating sufficient maturity to focus and manage their own schedule toward an abstract goal. This project is important for teachers considering implementation of a hands-on project like this in a middle school environment, in engineering and science talent development programs, and for professors interested in design experiences that their future students might have.

Introduction

The engineers of tomorrow are the children of today. One way to potentially make this vision a reality is to inspire and expose young students to engaging hands-on learning experiences that foster positive conceptions of engineering at a young age. Engineering design projects are one way to achieve this goal, since design is hands-on and involves creativity and problem solving. Additionally, engineering design projects can be done in teams to promote teamwork and interpersonal communication skills in the classroom.
Rube Goldberg (1883 – 1970) was an engineer turned cartoonist who drew incredible machines that completed simple tasks, such as turning off a light switch, in as complex of a way as possible. His cartoons were meant as a social commentary on how technology to solve simple problems is often needlessly complex, but this context provides an excellent context for children to learn about engineering design. Combining Rube’s ideas with an engineering design process gives students an opportunity to have positive experiences where they have a lot of room to explore and be creative while still following an engineering design process and understanding the basic process that engineers go through to design. These positive experiences could encourage students to consider careers in engineering and science. As engineering educators, it is important for us to understand how children who might become future engineers can learn an engineering design process as preparation for college experiences.

This paper seeks to further illuminate the question of how to teach children an engineering design process in the fun context of Rube Goldberg machines. It also emphasizes linking research and practice, with an emphasis on informing each from the other.

**Problem Statement**

Rube Goldberg activities have been used in K-12 and post-secondary classrooms throughout the country to teach science and inspire creative discovery for many years. Several studies have been done to describe implementations of Rube Goldberg curricula in a variety of educational settings, but few have attempted to investigate and learn from the process that the students go through and the products that they create. This paper examines how an engineering design process was taught to middle school students in order to provide a systematic way to design and build Rube Goldberg machines in an educational setting.

This study seeks to explore the following research questions, in the context of 5th and 6th grade students enrolled in a talent development program:

1. How do generated design ideas evolve across different stages of the design process?
2. How do group interactions influence design process outcomes?
3. How effective is teaching an engineering design process?

**Theoretical Framework**

In the research questions listed above, a common thread is the implementation of a pedagogy based on an engineering design process. Engineering design processes are very well studied (with some suggesting that they apply unnatural structure on design), with numerous established textbook process models in existence that are taught to engineering students worldwide. While the models are strictly different, the basic ideas behind their steps were combined and simplified into four basic steps for presentation to students: brainstorm, design, build, and test, with an optional iterative loop from test back to design. This provided a solid foundation for the students to learn the fundamentals of engineering design.

Another important aspect of this learning environment was the use of teamwork to both optimize the designing and building process, but also to teach students about cooperation.
According to Grambo\textsuperscript{5}, gifted students can learn about teamwork through cooperative learning. Patrick et al\textsuperscript{6} discussed the use of cooperative learning with gifted students, and further concluded that cooperative learning can be beneficial to both gifted and non-gifted students when higher levels of understanding are emphasized. That justifies the use of teamwork as an essential part of the curriculum, since one of the main reasons for gifted students to be sent to enrichment programs is to be in an environment where they can interact with like-minded peers.

Saturday talent development programs can be an alternative strategy for children who need more advanced content in a specific field. Children are usually taken to programs outside of regular schools, such as university summer camps and Saturday talent development classes. These types of programming offer several benefits to students, such as exposure to advanced content in diverse subject areas, highly qualified instructors, and interaction with like-ability peers in a learning environment where the students feel safe to be themselves\textsuperscript{7}. Special talent development programs can also provide affective gains in participants’ self-esteem, self-efficacy, and academic motivation and these gains may lead to greater success in school after attending such programs\textsuperscript{8}.

By providing additional enrichment opportunities that may not be part of the regular school experiences of some students, Saturday talent development programs provide many benefits. These benefits include maximizing achievement in basic concepts and skills, providing an adequate pace and level of activities, improving self-awareness and the understanding of one’s own ability level, interests, and needs, increasing independence, and teaching self-direction and discipline in learning\textsuperscript{9}. Parents of students taking the class are informed that it is challenging and that students who do not show high-ability or interest in the topic of the class may not benefit as much from the program.

**Methods**

*The Class*

The environment for data collection for this study was the Spring 2008 session of a Saturday talent development program. Students drawn to this program tend to be part of “gifted and talented” programs in their school systems. Usual measures of giftedness in schools are standardized and IQ test scores, however many students who participate in these programs are referred by parents or teachers since the primary goals are talent development and inclusion. Students or their parents choose to join particular classes based on their interests and priorities in wanting to develop their talents in particular ways.

The goals of the class were to meet the needs of students by creating a challenging differentiated learning environment where students could learn both through formal teaching and hands-on discovery. By having students work in groups, we created a project-oriented environment that promotes significant peer interaction. The students also learned and applied an engineering design process to the problems that they faced. Finally, students worked to understand the science and engineering concepts used in the Rube Goldberg machines that they built.
The class had a total of eighteen contact hours divided across six Saturdays. Each group designed and built 2-3 modules of a Rube Goldberg machine over the duration of the class and then connected them together into a larger multi-module machine for demonstration in the last class. The first class consisted of an introduction to the idea of Rube Goldberg machines, a brief pre-assessment, and an interest inventory. Students were then introduced to basic mechanics concepts, followed by brainstorming activities to facilitate group cohesion and camaraderie. Students spent the remainder of the class beginning to apply an engineering design process (brainstorm, design, build, and test) to the first modules of their machines. During classes 2 and 3, students completed designs of their first modules and proceeded to build and test them. Brief introductions to electricity, magnetism, and fluid mechanics were given, and brainstorming and design work began for the second modules. The fourth class was used to complete the design of, build, and test the second modules. Class 5 was spent completing the second modules and integrating and testing them together with their first modules. In class 6, groups reassembled their machines and tested them again before their final demonstrations to family members and classmates.

The Instructors

This class had two instructors, who were in charge of developing the curriculum and leading class activities and two course assistants, who worked directly with groups making sure they were engaged in the proposed activities. Instructor 1 was an Engineering Education graduate student who has 8 years of experience teaching college students, in addition to facilitating a number of community science and engineering outreach activities for 15 years. He also founded and led a two-time collegiate championship-winning Rube Goldberg team for a number of years. Instructor 1 brought in his experience with Rube Goldberg activities and his interest in teaching design. Instructor 2 is a graduate student in a Gifted and Talented program who has 11 years of experience teaching English as a second language in regular schools and language institutes. In addition, Instructor 2 had significant experience teaching middle school students and his knowledge of high-ability students and talent development programs. Both instructors were very interested in learning about the others’ areas of expertise, and thus a team teaching and co-mentoring environment was built to improve the quality of the classes. The two course assistants were undergraduate students in education programs looking for field experiences with high-ability students. One of the course assistants was double majoring in elementary education and special education and the other course assistant was a social studies education major. Both course assistants developed great rapport with students and helped make the students experience much smoother.

The Students

The participants in this study were fifteen 5th and 6th grade students enrolled in a Saturday talent development class entitled “Rube Goldbergineering.” Most attended schools in the area, but some came from other parts of the state to participate. Four of the students were part of a program to provide enrichment opportunities for children from low socioeconomic status backgrounds, bringing even more diversity to our sample (particularly with the representation of students from rural, suburban, and urban areas). The sample was made up of twelve boys and three girls, some of which had ADHD, anxiety disorders, or mild autism. The class was broken
into four teams: 3 of which were made up of all boys and a fourth made up of three girls in the class. We decided to have groups of same gender because students of that age group tend to prefer working in same-gender groups. This choice was based on one of the author’s experience teaching students of that age level and the fact that most of his pre-adolescent students are usually more comfortable and prefer working in same-gender groups.

Data Sources

A variety of data were collected during the class. A student interest inventory, conducted on the first day of class, provided a glimpse into what the students like to do. A pre-assessment, also conducted on the first day of class, was used to determine the background each student had with Rube Goldberg and related activities. Artifacts of the brainstorming process were collected in the form of lists and sketches made by the students. Design sketches were also collected, as well as the final posters that teams made including sketches of the final machine design and a written sequence of steps. Pictures were taken throughout the class, and videos of the final demonstrations were made. The two instructors kept reflective teaching journals, and evaluations measured the students’ perceptions of the class. These data were collected and electronically stored (e.g., the sketches were scanned) during the class in a master file.

Data Analysis

We analyzed the data collected during our study using a grounded theory framework\textsuperscript{10}. This qualitative research framework involves analyzing data without preconceptions of an existing theory for the purpose of generating a new theory through induction. Results can then speak independently (but can be connected to) established models. While this research is not directly generalizable, it does help better understand phenomena in an exploratory way that can build greater understanding and provide directions for future research.
Results

The results obtained for each research question are described below.

Research question 1: How do generated design ideas evolve across different stages of the design process?

The class was structured to scaffold the design process by providing worksheets for students to complete. Worksheets for brainstorming themes and modules were combined with plain paper available for design sketching. A wide variety of artifacts were produced. During brainstorming, many ideas came up that were related to their task of delivering a candy bar. Two teams struggled to generate and agree on nearly any ideas due to problems with the dynamics of their teams, and ended up with themes that “seemed to be tied to their team names” (Instructor 1 journal, 1/26/2008). The other two teams provided a very interesting glimpse into the lives of children in this age group. Some of their ideas were related to the task, others connected to videos and example machines we had shown them in the past, but most were related to the things that make up their daily lives. Team 1 particularly excelled at this process, generating 24 different theme ideas before voting on a final theme of “water” (see Table 1).

<table>
<thead>
<tr>
<th>Team</th>
<th>Ideas generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team 1 (3 girls)</td>
<td>Willie Wonka, bookworms, drawing, shopping, roller skating, pop star, school, outer space, science, computer, junk food, chocolate, baseball, football, biology, holiday, messy room, swimming, math, seasons, carpentering, safety, <strong>water</strong>, family</td>
</tr>
<tr>
<td>Team 2 (4 boys)</td>
<td><strong>Chocolate factory</strong>, Willie Wonka, Hershey Park, Martian chocolate</td>
</tr>
<tr>
<td>Team 3 (4 boys)</td>
<td><strong>The machine ate our Milky Way</strong></td>
</tr>
<tr>
<td>Team 4 (4 boys)</td>
<td>Football, Star Wars, Legos, cars, <strong>robots</strong>, school, mindstorms, people, soccer, hazers, building materials, factory, buildings, science</td>
</tr>
</tbody>
</table>

Table 1: Theme ideas (**bold is the final chosen idea**)

Teams then migrated to brainstorming and sketching module ideas during the next several classes. All teams struggled with this idea to some extent. The model of brainstorming presented was that teams should generate as many ideas as possible and then pick a subset of those ideas to put into their final design. Two teams suffered from individuals who “had a problem of drawing out entire machines during the brainstorming stage” (Instructor 1 journal, 1/26/2008) and would then argue within their groups about incorporating additional ideas beyond the individually proposed design. The proposer would often take offense to suggestions of changes, significantly increasing the friction within the teams. Other teams were able to generate ideas as a team during brainstorming, such as Team 4 (see Figure 1).
Following module brainstorming, the teams formally moved into a design stage where they formalized the ideas generated during brainstorming. Most teams had trouble generating ideas that they were not going to use, so the “students had already reached conclusions on what they wanted to put into their machines” (Instructor 1 journal, 2/2/2008) and just needed to draw out their designs. Herein lay the challenge: the students were reluctant to draw out their designs. Some cited difficulties drawing, while others were simply disinterested and wanted to begin building. Others enjoyed drawing and drew reasonably complete module designs that evolved from prior brainstorming efforts (see Figure 2).

Following sketches of the designs of their individual modules, teams built the modules independently. Most of the final modules “that the students chose to design are realistic for them to build” (Instructor 1 journal, 2/2/08), suggesting that the students understood that some of their more creative ideas were unrealistic to build. Designs often changed during implementation (as is to be expected) due to the realities of materials and physics. For instance, Team 4 had to redesign a switch trigger because the original switch they wanted to use could not be triggered by the lightweight car that was trying to push it.

As teams moved toward integration, they were asked to draw how they envisioned that their modules would connect together. Some ignored this request and continued to build (often
because their implementations had not stabilized enough for them to draw out a “final design” in their eyes), while others such as Team 4 were able to create final sketches that were reasonably accurate (see Figure 3).

As teams integrated their modules together, many surprises were encountered. Some teams, such as Team 4, realized that their modules would need to be at different heights in order to be connected together, and reflected this in their designs (see Figure 3). Other teams had no idea that their modules needed to be at different heights and spent much of the last class coming up with creative workarounds to connect their modules together. This process ended with final lists of steps and drawings for three of the four teams. Due to time constraints, no teams had time to do significant redesigns of individual modules for purposes other than connecting them together. However, the overall improvement in the quality of their design products was clear, as their drawings had more detail and labeling than when they started brainstorming at the beginning of the class.

Research question 2: How do group interactions influence design process outcomes?

Teamwork was a challenge for the students. Gifted children often prefer to work alone than to work with others. The notion of individual roles in teams was introduced in order to facilitate better teamwork, but the students did not adopt the roles well and usually fell back into each person working independently. That can be illustrated by the sketch in Figure 4, which was generated during the first brainstorming session.
Although this was supposed to be a group endeavor and groups were supposed to make sure everyone’s ideas were included, the label “My Idea!” used on this sketch shows that perhaps this student did not understand the spirit of the class and decided to identify his idea. From our observations, we could see that other similar cases happened and that, although teams had a chief idea officer, who was in charge of leading brainstorming and making sure all ideas were discussed and considered for inclusion in the final design, often times the designs ended up having mostly ideas from one or two members in the group. As a result, the brainstorming time typically consisted of each individual drawing a complete machine on a piece of paper and then trying to figure out with the team either which machine was better or how the machines could be connected together. This was not in the spirit of true collaboration, and was something that we as teachers worked very hard with the students to overcome.

One good example of the aforementioned issues was Steven who was a very gifted and creative student and who, from the first class, showed a lot of potential to work on the task we proposed. His interest inventory included activities related to Rube Goldberg and engineering and his pre-assessment and his participation in class showed that he had quite a lot of knowledge of physics and the concepts used to create Rube Goldberg machines. From the first class, it looked like Steven would definitely succeed and be able to create great Rube Goldberg machines. However, Steven was placed in a “problem group” and his trajectory went from promising at the beginning to struggling to get his project done in time towards the end of the course. Steven was in a group that had a student who was not interested at all in the project and missed half of the classes; another student who could not follow the pace of the class and, thus, could not help very much; and another student who had great ideas, but who had a really hard time working in a group. Steven and this last group mate argued all the time and neither of them could compromise whenever they had to decide whose idea to use and that caused the whole group to collapse. At some point, Steven decided he would finish the project even if he had to do it by himself and that is exactly what happened from then on. However, his project included some ideas by the other group members and, since he wanted to prove that his ideas were better than his peers’, he ended up having to do much more than he could and also had a hard time getting ideas from his sketches built. Had he been working by himself, he would probably have remained within his comfort zone, but that was not what happened, so being in a group was probably not beneficial to Steven.
An example of how a team can work together to face adversity and complete a task is the case of Sandra and of how the same team can stick together when one member becomes a problem, who was in a group with two other girls. Sandra also showed a lot of potential from the beginning, but some of her qualities helped her overcome most of the difficulties faced throughout the process: she could easily compromise and she didn’t give up even when things were not working for her group. Her solutions to problems were usually accepted by her group mates or were discussed with the group, so that everyone was listened to and the best ideas were used. One good example of how group interactions in that group were positive and contributed to the successful completion of their project was the extensive list of theme ideas the group generated during one of the first class. That was the perfect example of how brainstorming should happen. However, towards the end of the course, one of the members of Sandra’s group started moving in a different direction and Sandra and the other group mate simply continued working on their project and tried to include the non-conforming peer as much as possible, but without compromising their project and instead of simply engaging in useless arguments.

Research question 3: How effective is teaching an engineering design process?

Overall, the engineering design process was difficult for the students to use. During the first day of class, “the kids seemed very receptive” (Instructor 1 journal, 1/26/08) to learning an engineering design process. When it came to applying it, though, the students were primarily interested in building and didn’t want to take the time to do planning and design work before building. This could be due to the fact that few students had experience designing before but most had built things at home and/or school prior to the class. We were able to get them to design by scaffolding and staging the class in such a way that they could not build until they had designs, but this had a very forced feeling to it.

Many of the problems stemmed from students not differentiating stages of the design process and instead trying to immediately draw the final design (Instructor 1 journal, 1/26/08), as was described in research question 1. This was the case if they did documentation at all, which many groups would rather not have had it been their choice. “Guiding the students that the drawings should be done during particular parts of the class seems to be working”, but the instructors questioned whether “this is a natural way to do design” since it was forced and since the students were “not going back and revisiting the design stage very much” (Instructor 1 journal, 2/2/08).

While generating design documentation was a challenge both for the students and for the teachers trying to encourage the students, it did have some distinct advantages. Besides providing a baseline for students to refer to during building, written designs also provided a record of decisions made in the past and allowed students who had missed class to get up to speed faster. Design drawings also helped mediate several arguments among team members who remembered the past differently. These drawings also improved significantly over time, as was discussed in research question 1.

On the last day of class a survey to assess the students’ perceptions of the class was administered by the course assistants. My Class Activities (MCA) is an instrument that measures students’ perceptions of four dimensions of motivation in classroom environments. The four dimensions are Interest, Challenge, Choice, and Enjoyment. MCA was normed using a
national sample of both gifted and non-gifted students and showed alpha reliability internal consistency estimates ranging from .75 to .92 for middle school students. Scores for students in the Saturday enrichment program on the four dimensions of MCA usually range from 3.30 (Choice) to 4.40 (Enjoyment). Students in our class attributed scores ranging from 3.36 (Choice) to 4.50 (Enjoyment) to our class. Table 1 contains the average MCA scores for other Saturday enrichment program classes and for our class in the semester in which we taught the course.

<table>
<thead>
<tr>
<th></th>
<th>Rube Goldberg</th>
<th>All Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest</td>
<td>4.16</td>
<td>4.23</td>
</tr>
<tr>
<td>Challenge</td>
<td>3.62</td>
<td>3.51</td>
</tr>
<tr>
<td>Choice</td>
<td>3.36</td>
<td>3.35</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>4.50</td>
<td>4.43</td>
</tr>
</tbody>
</table>

Table 2: Mean MCA scores for Rube Goldberg and for other classes

Another source of evaluation of classes are students written comments about the classes they take in the Saturday enrichment program, which are collected at the same time as MCA. Most of the comments were positive and indicated that students were satisfied with the results of the class. When asked about what they liked the most about the class, most of the students said they really enjoyed building and some of them said they liked the creation process and being able to use their own ideas in their projects. When asked if they would like to tell us anything about the class, students’ comments ranged from “fun” to “awesome” (with some of the students not responding to the question).

Conclusions

Rube Goldberg engineering design activities can act as a bridge to expose middle school students to the world of engineering, where design is a central activity. They also serve to bring people from a variety of backgrounds together around a common cause, where they can learn from and with one another as they tackle engineering challenges. Engineering educators are faced with many of the same challenges when teaching new classes of first-year students. Students are coming from a variety of backgrounds into a new environment where they know few people and are looking for direction. Rube Goldberg engineering design activities can provide team-building experiences for students, in addition to providing them with early exposure to engineering design in a challenging yet interesting context. We can learn from the experiences that these middle school students had, and try to provide similar successful experiences to students enrolled in first-year engineering programs.

The class described in this paper provided an experience for students in learning about engineering and being successful working in a team and doing an engineering project. Since design is central to many engineering tasks, this project is a more realistic hands-on way to expose students to engineering thinking. Their thinking sharpened over the course of the class, as evidenced by the improved quality of their design products and increased complexity of their designs. This alone can help more students develop and maintain an interest in engineering, even if they had never considered it as a viable option before.
Teamwork was a challenge for the groups, but the lessons they learned can help us understand students entering our first-year classrooms who may become future engineers. The middle school students had trouble applying a design process, taking leadership roles, compromising, and demonstrating sufficient maturity to focus and manage their own schedule toward an abstract goal. These findings are consistent with Crismond’s work reviewing research comparing “beginning” and “informed” designers in a variety of settings. The novice designers in this class tended to “fixate on first design ideas,” “design in haphazard ways,” and “have a generalized, unfocused way of viewing tests and troubleshooting their ideas.” These are the same kinds of issues we encounter when teaching freshmen, many of who are also “beginning” designers. Engaging students in an engineering design project helps give students critical experience in these areas.

Based on our findings, we have suggestions for educators who plan to use similar activities in teaching kids of a similar age group. The first suggestion is establishing shorter-term goals for students and finding ways to engage students in whole-class activities. Having each group build a module and then asking groups to integrate their modules into a whole-class machine could accomplish this. That can create a sense of accomplishment of a task after a module is completed and it may also engage all students in the classroom in trying to get their modules to work since failure in any of the modules could cause the machine as a whole to not complete its task without human intervention. Another suggestion is removing the leadership roles and asking all students to contribute equally in their groups.

Adding more structure to the way tasks are described is also important. More scaffolded experiences could help students accomplish their goals and complexity could be added as students become more proficient at designing and building Rube Goldberg machines. In order to help students understand the importance of having sketches before building machines, we could start by drawing machines as a class on the board and then move on to asking groups to brainstorm and design their own modules.

Overall, the challenges encountered during the class have led to improvements in the curriculum for future offerings of the class. The students enjoyed the course, rating it consistently high with other classes offered at the same time. Despite the challenges encountered, the class did work and served its purpose of teaching students an engineering design process. Similar ideas could be adapted to first-year classes seeking to provide a bridge into engineering for their students. We hope that this experience will lead to a greater interest in engineering among the students who participated, and that others will have the chance to learn from the experiences described.

Limitations and Suggestions for Future Research

This study is not without limitations and some of them stem from the choice for qualitative methods. The sample used in this study was small and thus we do not intend to generalize our findings to all 5th and 6th grade students in talent development programs. Our sample was also rather heterogeneous, which makes generalization challenging, but that also allowed us to see how our curriculum worked with different types of students. Unfortunately, we were only able to use the curriculum with one group of students and, since participants were participating in a
regular educational program, we could not distinguish between groups or students to compare
different approaches and had to provide everyone with the same experience. Finally, because this
study was done in an educational setting, our focus was primarily on teaching the class and not
on collecting data. Our observations of the class may have been limited and biased since we were
primarily in instructor roles and not researchers. Our reflective teaching journals provided
informative insights into the experience of teaching the class, but they were not always written
right after the class was over and that may have created some bias as well.

Future iterations of the class could include some of the suggestions described above such as a
more scaffolded approach to the tasks and changes to the way teamwork was approached.
Having a larger sample would probably not help, but we could have different groups and use
different approaches to teaching Rube Goldberg with each of the groups. That way we could
compare how slightly different models work with similar students. Another idea for
improvement would be having a more homogeneous group. As to data collection improvements,
a study that included various data sources, such as observers with an observation protocol,
interviews with some the students in the class, and videos could help with triangulation of data
sources. Finally, this study could be reframed into an action research framework so that we could
try to improve the curriculum based on our experience teaching different students.

Bibliography

   Hill.
   London: Springer.
   20-1.
   the Education of the Gifted, 29(1), 90.
   special programs and support from others on acceleration, achievement, and aspirations. In K.D. Arnold,
   K.D. Noble, and R.F. Subotnik (Eds.), Remarkable women: perspectives on female talent development
    Chicago: Aldine.
    of interest, challenge, choice and enjoyment in their classrooms. (Instrument). Mansfield Center, CT:
    Creative Learning Press.
12. Crismond, D. Contrasting strategies of beginning and informed designers: one representation of learning
    progressions in engineering design.