Using a Multidisciplinary Team-Based Challenge to Promote Brainstorming and Prototyping of Medical Devices

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**Abstract –** Multidisciplinary teams of engineering and non-engineering students are challenged to remove a foreign object from a child’s ear canal. Each group is provided with a model ear canal and challenged to remove objects of different shapes and materials. The experience of iterative problem solving serves to encourage brainstorming and practice the prototyping process, which each team should complete in their over-arching design projects to be successful. Surveys taken from the students before and after the prototype challenge showed they learned more about the brainstorming method they used, but also learned what worked well for other groups. Student feedback indicates that this simple activity prepared them to tackle the larger challenge of developing a solution to their own design project as part of the Biomedical Engineering Capstone Design course.

***Keywords:* Prototypes, Medical Device, Brainstorming, Foreign Object, Ear Canal**

# 1. INTRODUCTION

Within a capstone design course, an activity based on removing a foreign object from a child’s ear canal was used to emphasize the creation of prototypes and testing to solve a problem. While this challenge was not directly related to the design project of team specifically, it was used to incorporated the theme of biomedical engineering and medical device into a miniature challenge that could be tackled during a 3-hour period.

The Biomedical Engineering Minor Capstone Design course offered at the University of Toronto is unique because engineering and non-engineering students collaborate over two semesters on a design project. These multidisciplinary groups have a great advantage because students in Life Science programs (e.g., molecular genetics or neuroscience) bring substantial knowledge of human health to their teams, while the engineering students generally bring more experience with engineering fundamentals and design, including idea generation and prototype development. Therefore, an activity was created to provide a common foundation for all students that encouraged brainstorming and prototyping during the build phase of the capstone design course

The purpose of this activity is to start the second semester with a fun and engaging activity and intended outcomes are to: 1) apply brainstorming techniques, 2) recognize the steps in the design process, 3) produce a working prototype, 4) evaluate alternative designs, and 5) validate a final solution. Students are instructed to identify key requirements (i.e., do not puncture the ear drum) before using different brainstorming techniques to develop concepts and build prototypes. In order to develop and test the prototypes, model ear canals are provided to give realistic physical constraints to the problem. Each team progressed from a larger, low-fidelity, mock canal to a smaller, high-fidelity, 3D-printed ear canal. The level of difficulty in removing objects is adjusted by placing different shapes and materials in the ear canal models to test the extent that their prototypes met the requirements identified by each team.

# 2. BACKGROUND

A major design experience in the final year of undergraduate engineering studies that uses knowledge and skills from earlier course work and incorporates realistic constraints, defines a “capstone” design project course [1,2]. In general terms, this type of course should complete the connection of project- or problem-based learning activities [3] from the first year (cornerstone), through a design spine, to final year (capstone) [ref design spine]. The intended outcome of this curriculum is that students will be able to identify basic needs, analyze open-ended problems, propose solutions to problems, and evaluate their designs based on realistic testing [4,5].

The design cycle is presented in this course to students as a straightforward; design, build, and test framework. Each of these phases is expanded to highlight specific actions taken at each step. The design phase is expanded to: 1) defining the problem with research, interviews, and observations and 2) collecting information to synthesize the function, attributes, and specifications that can be used to assess whether a solution meets a user’s needs. The build phase is expanded to: 3) image what potential solutions could be and then choose the most promising to 4) develop into a plan, prototype, or product. The test phase is expanded to: 5) measure a response from a proof-of-concept, benchtop, animal, human, or other experiment and 6) improve the design as a result of studying the results and implementing changes. [Arushri - Is there any reference for my simplistic design, build, test framework?]

Ideation often starts with inspiration and imaging what kind of form or structure a solution might have. Realizing that a large volume of ideas are necessary to produce a single good idea, brainstorming [6] is a process that helps spark the development of new ideas and creates innovation by connect existing ideas. While many methods of brainstorming exist, only 4 techniques were emphasized in this team-based challenge. The 6-3-5 method [7] was modified for a group of 4 but still involved each student writing down 3 ideas on a worksheet for 5 minutes and then passing the worksheet to the next team member so that after 20 minutes there were 48 ideas generated. The theme of biological inspiration was used to trigger unstructured brainstorming by using the website asknature.org [8], where ideas inspired by nature are linked to engineering designs or principles. An example of biologically inspired design would be the how timber beetle larvae inspired the chain saw [9]. Mind mapping [Arushri - find reference] was used as a framework to structure brainstorming in different areas and identify unexplored gaps; for example, a mind map could be created based on engineering disciplines and ideas related to mechanical or electrical engineering would be explored and a gap of chemical engineering ideas could be identified. Finally, brainstorming was stimulated, in general, by asking the following question: “How might we …?” [Arushri - find reference], which emphasized practical ideas that focused on *how* a solution would be solved. For example: How might we create suction to remove hard objects from an ear canal?

Throughout the design process, prototypes are useful tools to communicate ideas and test working solutions [10,11]. To encourage active learning some capstone design courses embed short duration design challenges; for example, in the form of a bootcamp [12] or an introductory exercise for team-building at graduate-level [13]. [Arushri – see if you can find other examples of “prototyping” exercises/challenges].

# 3. METHODOLOGY

An introductory lecture on ideation was completed before the prototyping challenge activity was attempted by students in a subsequent (3-hour long) design studio session. The lecture took place in a traditional theater environment and the prototyping challenge activity used the design studio facilities available to undergraduate students enrolled in the biomedical engineering capstone design course.

The lecture focused on the actions that each team could use to imagine ideas for solutions to their overall design projects. After a range of brainstorming techniques were presented, the students completed an activity in class that focused on practicing one specific technique. The goal of this activity was to incorporate a jigsaw-style [add ref for jigsaw – there is a book at CTSI but I forget what it’s called] cooperative learning activity. The whole class was exposed to 4 brainstorming techniques: 1) 6-3-5 method, 2) biological inspiration, 3) mind mapping, and 4) “How might we …?”. Each technique was assigned to a single team and each team would practice their assigned technique to solve the problem of how to remove a foreign object from an ear canal. This activity was conducted for approximately 20 minutes, followed by a short debrief that communicated how well each team felt that their assigned brainstorming technique helped them. A final, much more extensive, debrief was also presented at the completion of the prototyping challenge. Therefore, this activity served two purposes: 1) to give students a head start on the brainstorming process before the prototyping challenge occurred in the laboratory period and 2) to complete the jigsaw activity by sharing with the other teams how well a particular brainstorming method worked in terms of generating good ideas that could be easily prototyped.

After the brainstorming activity was completed in class, each student completed a pre prototyping challenge survey. Each student rated their knowledge of each brainstorming technique on a scale of 1 to 7 (1 = unacceptable, 2 = very poor, 3 = poor, 4 = satisfactory, 5 = good, 6 = very good, and 7 = excellent) and they also ranked, from best to worst, how they felt that each technique would yield results in the, yet to be completed, prototyping challenge. After the prototyping challenge was completed in the design studio, the same survey was given to each student. The only difference was that they now ranked, from best to worst, how they felt that each technique *yielded* results in the prototyping challenge they just completed. The survey questions are shown in appendix A.

At the beginning of the prototyping challenge, a brief overview of the challenge was presented and each team was reminded of which brainstorming technique they were to use during the first 30 minutes of the studio session. Each team was first presented with a low fidelity ear canal model based on an instruction set found on the teachengineering.org website [14]. The model had 1-inch long, 1/2-inch diameter PVC tubing to mimic the ear canal and a membrane on the distal end to represent the ear drum (see figure 1). The challenge for each team was to remove objects of various sizes (e.g., gel beads, silicone putty ear plugs, miniature shells, fuzzy pompoms, etc.) without puncturing the ear drum. Each team was given access to a selection of hand tools (e.g., Dremel® tools, wire cutters, scissors, glue guns, tape, etc.) and an assortment of easy-to-use construction materials (e.g., wire, springs, balsa wood, wood craft sticks, floral foam, straws, etc.) to create prototypes that could remove the objects used as mock-foreign object.

Once students found a way to remove the foreign objects on the low fidelity scale, they had to move to the smaller scale, 3D printed model, which constrained the size of the ear canal to ~ 5 mm in diameter. After approximately 2 hours each team had moved from brainstorming to realizing their ideas with quick, easy-to-construct prototypes. A final showcase of the prototypes created by each team was linked to a class-wide debrief of how the brainstorming technique influence the devices they created. The goal was to complete the jigsaw cooperative learning exercise by sharing the knowledge gained by each team about a specific brainstorming technique they put into practice.

# 4. RESULTS AND DISCUSSION

[Add plot here, maybe a bar chart of the knowledge pre/post, with standard errors?]

The results of asking students to rate their knowledge of each brainstorming technique (i.e., 1; modified 6-3-5, 2; mind map, 3; “How might we …?”, and 4; biological inspiration) after lecture but before the prototyping activity revealed each to be fairly equal and between the good and very good levels. After completing the prototyping challenge, the biological inspiration technique received the greatest increase in knowledge (approaching the level of very good). In this case 5 students rated that their knowledge increased and only 1 student rated a decrease. On the other end of the spectrum, the “How might we …?” technique had no change in knowledge after the prototyping challenge, as only 1 student rated an increase but 3 rated a decrease in knowledge. The other techniques received negligible increases, as only a slightly greater number of students felt that their knowledge increased regarding the modified 6-3-5 and mind map techniques.

The results of asking how student’s rated their level of knowledge, suggest that having each team share their results after the prototype challenge had some small effect on increasing the knowledge of others. These relatively minor effects are likely due to the passive sharing of knowledge after the completion of the prototyping challenge. While this overarching activity promoted interaction within and between teams, it would be expected that modifications to the challenge, that incorporated positive interdependence and individual accountability, would further increase the knowledge of students regarding each brainstorming technique after the completion of the prototyping challenge.

Table 1: Ranking of Methods that Each Student Felt Would Yield (pre) and did Yield (post) the Best Results

|  |  |
| --- | --- |
| Pre Challenge | Post Challenge |
| Mind map | Modified 6-3-5 |
| Modified 6-3-5 | Mind map |
| “How might we …?” | Biological inspiration |
| Biological inspiration | “How might we …?” |

(Brainstorming techniques ranked best are listed on the top and worst are listed on the bottom)

Table 1 shows the collected results of asking students to rank the brainstorming methods they felt would yield the best results, before participating in the prototyping exercise and the rank they felt yielded the best results, after participating in the prototyping exercise.

The questionnaire given to students after completion of the prototyping challenge asked students if they thought that the activity was more effective at delivering information compared to a normal lecture format. Out of 11 responses: 3 strongly agreed, 5 agreed, 2 were neutral, and 1 disagreed. A representative comment from a student who strongly agreed and was:

*“It was a really applied way of learning … and it gives us an idea of the prototyping process before we actually start.”*

# 5. CONCLUSIONS AND FUTURE WORK

The data indicate that this activity made students more comfortable in the brainstorming technique they used and learned from the experiences of other teams. Both the data and results of student feedback suggest that the sharing of knowledge between teams increased individual knowledge and the majority of students prefer the experiential activity to a normal lecture format. Students also indicated that they liked the teamwork and “hands on” aspects of the activity and felt that practicing the creation of low-fidelity prototypes in the beginning of the ideation process was beneficial.

## 5.1 Limitations

Some students felt that the challenge did not relate to their individual projects, which was reflected in the following comment:

*“It would be more helpful if the topic was geared to our own project rather than the ear canal problem.”*

Other students, who disagreed or who were neutral on whether the activity was better than a normal lecture format, did not see the connection between this activity and the broader use of prototyping in the ideation process. For example:

*“[I] did not understand the different types of prototyping methods. [This activity] was not helpful in understanding of how to prototype real world concepts.”*

Only 16 students were enrolled in this course and only 12 participated in both the pre and post challenge survey. The sample size of students participating in this activity was small and therefore no statistical testing was attempted at this preliminary stage of analysis.

## 5.2 Future work

Keeping with the theme of biomedical devices, the main task of removing a foreign object from an ear canal will continue to be used in the capstone design course and improved by offering more prototyping materials and realistic ear canal analogues. One way to increase the realism of the ear canal would be to use a realistic training simulator for otoscopy; for example, the OtoSimTM system [15]. The possibility of extending the prototype challenge to allow for 3D printed designs to be created and tested will also be considered for future challenges.

Other future work will be dedicated to improving the communication of the link between the brainstorming techniques covered in a lecture format/e exercise and the prototype challenge completed in the design studio to address the comments of some students, for example:

*“It would be better if we are informed about the activity beforehand.”*

# APPENDIX A: PROTOTYPING CHALLENGE SURVEY

## A.1: Pre Prototyping Challenge Survey:

1) After the in-class brainstorming activity, how would you rate your knowledge of each of the following techniques?

Modified 6-3-5 (\_\_\_\_)

Mind Map (\_\_\_\_)

How might we …? (\_\_\_\_)

Biological inspiration (\_\_\_\_)

Where: 1= unacceptable, 2 = very poor, 3 = poor,  
4 = satisfactory, 5 = good, 6 = very good, 7 = excellent

2) Rank the brainstorming techniques in the order you feel will yield the best to worst results

1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
3. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
4. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## A.2: Post Prototyping Challenge Survey:

1) After completing the prototyping challenge and observing how other groups used their brainstorming techniques, how would you rate your knowledge of each of the following techniques?

Modified 6-3-5 (\_\_\_\_)

Mind Map (\_\_\_\_)

How might we …? (\_\_\_\_)

Biological inspiration (\_\_\_\_)

Where: 1= unacceptable, 2 = very poor, 3 = poor,  
4 = satisfactory, 5 = good, 6 = very good, 7 = excellent

2) Rank the brainstorming techniques in the order you feel *yielded* the best to worst results

1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
3. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
4. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## A.3: Feedback Questionnaire

1) For the prototyping challenge activity, do you think it is a more effective way to deliver the information than a normal lecture format? (circle on of the following)

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

2) In regards to the prototyping challenge activity, can you list at least 2 things that you like and 2 things you didn’t like? In which way do you think the activity could be improved?

3) Do you have any other comments?

**References**

[1] Hyman BI. "From Capstone to Cornerstone: A New Paradigm for Design Education". *Int J Eng Educ* 2001;17:416–20.

[2] Froyd JE, Wankat PC, Smith KA. "Five Major Shifts in 100 Years of Engineering Education". *Proc IEEE* 2012;100:1344–60. doi:10.1109/JPROC.2012.2190167.

[3] Dym clive\_dym@hmc.edu CL., Agogino aagogino@socrates.berkeley.edu AM., Eris ozgur@stanford.edu O, Frey danfrey@mit.edu DD., Leifer leifer@cdr.stanford.edu LJ. "Engineering Design Thinking, Teaching, and Learning.". *J Eng Educ* 2005;94:103–20.

[4] Crawley EF, Malmqvist J, Östlund S, Brodeur DR, Edström K. Rethinking Engineering Education. Cham: Springer International Publishing; 2014. doi:10.1007/978-3-319-05561-9.

[5] Taajamaa V, Eskandari M, Karanian B. "O-CDIO: Emphasizing Design Thinking in CDIO Engineering Cycle". *Int J Eng Educ* 2016;3(B):1530–9.

[6] Osborn AF. Applied imagination principles and procedures of creative thinking. New York: Scribner; 1953.

[7] Rohrbach B. "Kreativ nach Regeln–Methode 635, eine neue Technik zum Lösen von Problemen". *Absatzwirtschaft* 1969.

[8] "AskNature - Innovation Inspired by Nature" n.d. https://asknature.org/ (accessed April 21, 2017).

[9] Cox JB. Chain Saw. US2622636A, 1946.

[10] Berglund A. Two facets of Innovation in Engineering Education : The interplay of Student Learning and Curricula Design. KTH Royal Institute of Technology, 2013.

[11] Berglund A, Leifer L. "For Whom Are We Prototyping? A Review of the Role of Conceptual Prototyping in Engineering Design Creativity". *DS 73-2 Proc 2nd Int Conf Des Creat Vol 2* 2012:201–10.

[12] Guo X, Taajamaa V, Yang K, Westerlund T. "Capstone Bootcamp Concept Catalyzing Problem-based Learning". *11th Int CDIO* 2015.

[13] "Design for Extreme Affordability" n.d. http://extreme.stanford.edu/ (accessed April 20, 2017).

[14] "Designing a Medical Device to Extract Foreign Bodies from the Ear - Activity" n.d. https://www.teachengineering.org/activities/view/uva\_eardevice\_act (accessed April 21, 2017).

[15] "OTOSIM" n.d. http://otosim.com/ (accessed April 21, 2017).