University of Toronto
Faculty of Applied Science and Engineering
ASP112 & APS113
Conceptual Design Specifications (CDS)

Team #	017	Date	March 26, 2023

Tutorial Section	TUT0104
Project Title	Redesign of Storage Unit for Lab Equipment
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Please check off which components you are submitting for your assignment.
✓ CDS submitted as a PDF to Quercus with the following components:

- ✓ Cover Page
- ✓ Executive Summary
- ✓ Introduction
- ✓ Problem Statement
- ✓ Service Environment
- ✓ Stakeholders
- ✓ Detailed Requirements (FOCs)
- ✓ Generation, Selection and Description of Alternative Designs
- ✓ Proposed Conceptual Design Specification
- ✓ Measures of Success
- ✓ Conclusion
- ✓ Reference list
- ✓ Appendices
- ✓ Attribution Table

If any required components are missing, your assignment is considered incomplete. It will accrue standard late penalties until completed.

Executive Summary

Abigail Clapperton, a graduate student at the University of Toronto, has requested a redesigned storage system for separatory funnels. The client needs a safer way to store the equipment, since the current system currently causes the funnels to crack, raising safety concerns.

The funnels are currently stored at the bottom drawer of a storage unit in a lab at Lash Miller Chemical Laboratories with bubble wrap and soft cloth surrounding them in an attempt to prevent them from breaking. However, the opening and closing of the drawer still causes the funnels to collide with each other and the walls, leading to cracks. The lab group, consisting of eight graduate students and one undergraduate student, uses this equipment regularly, with at least one person using it per day, hence the drawer is opened frequently.

The design team has identified key functions, objectives and constraints of the design which will help meet the needs of the client as well as key stakeholder groups, which include other laboratory scientists, Non-Governmental Organizations (NGOs), corporations and unions. The design must be able to store the funnels in a way that prevents the funnels from breaking while staying within the drawer and meeting the design standards for lab design outlined by the University of Toronto. The design should also meet the objectives of reducing crack formation by limiting collisions, be cost effective for the lab group, and be easy to assemble.

Through idea generation, the design team was able to generate over 100 ideas using free brainstorming, Substitute, Combine, Adapt, Put to other use, Eliminate, Rearrange, Reverse (SCAMPER) and morphological charts. The team was then able to use idea selection methods, such as multi-voting, graphical decision charts and a weighted decision matrix to narrow the ideas down to the following three designs.

The first option is a polyethylene foam base which can be inserted into the drawer. The foam will have holes the shape of the separatory funnels and will be as deep as the radius of the funnel. The funnels will be organized by columns.

The second option is a frame made of poly-vinyl chloride (PVC) pipes that can be inserted into the drawer with separate, 3D printed holders. The holders will be placed the length of the funnel apart and the funnels will be placed in the indents provided.

The third option is styrofoam lining the base and the walls of the drawer. Wood dividers covered in polyethylene are placed to divide sections where each separatory funnel is stored.

After comparing the above designs against the current design and the objectives outlined, the team has selected the first option as the best solution for the client. For next steps, the team will carry out a low-fidelity prototype test using a styrofoam base to measure the movement of objects stored in a foam base to ensure the design will be effective in addressing the client's needs.

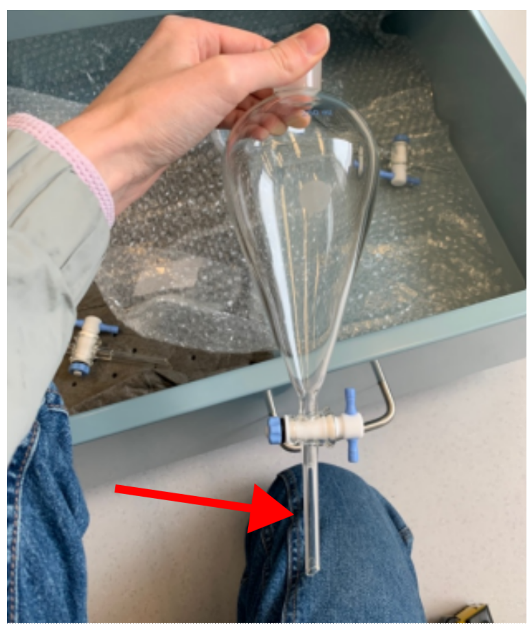
1.0 Introduction

Abigail Clapperton is a graduate student at the University of Toronto who often works with separatory funnels, a common type of equipment used in chemistry labs. She has requested a redesign of the storage system for the separatory funnels to improve safety for the funnels and those using it. The following document outlines the context of the problem surrounding the current storage system and the process the design team took to generate and select a new idea for the storage system.

2.0 Problem Statement

The separatory funnels are currently stored in the bottom drawer of a storage unit in the lab [1]. When the drawer is opened and closed, the funnels collide with each other and the interior drawer walls, causing star cracks to form (Figure 1) or for stems to break (Figure 2). Studies done on glass similar to borosilicate glass show that crack patterns, such as star cracks, can develop under subcritical force levels such as residual stresses [2].

While the equipment can still be used with a partially broken stem, it poses a safety hazard, as users may be cut by sharp pieces of glass. Furthermore, the star-shaped cracks are costly to repair, and the equipment cannot be used while being repaired.



Left to Right: Figure 1: Image of a star crack [3]; Figure 2: Separatory funnel with stem highlighted [4]

The storage unit lacks adequate protection preventing the separatory funnels from contacting each other or the walls. The client has not found any retail solutions to safely store the funnels in drawers; currently, bubble wrap and cloth are used to mitigate the impact of forces on the drawer contents. Retail solutions include racks that suspend the funnels in the air, but these do not fit within the drawer where the funnels must be stored (Figure 3).

Figure 3: Current retail storage system for funnels [5].

The client needs a design limiting damage to separatory funnels and other lab glassware. The scope pertains to the drawer of a storage unit in a laboratory; the funnels or equipment will not be changed, but attachments to prevent breakage may be added. The design will be used year-round and at all times of day [6].

3.0 Service Environment

The drawer that requires the storage system is located in the Lash Miller Building, 80 St George Street, Room 518. Some aspects of the physical environment that would need to be considered include:

- Temperature: ~20° Celsius year-round (Figure 4)
- Humidity: ~10%, with minor seasonal changes as the lab is not climate controlled (Figure 4)
- Three sizes of separatory funnels (Figures 5, 6)
- Dimensions of drawers: 5.5 inches by 19 inches by 45.5 inches [4]

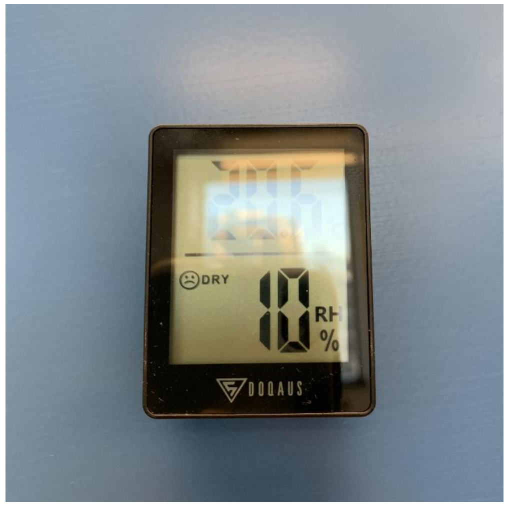


Figure 4: Temperature and humidity of lab on March 9th, 2023 [4]

Figure 5: Overview of lab equipment currently stored in the drawer.

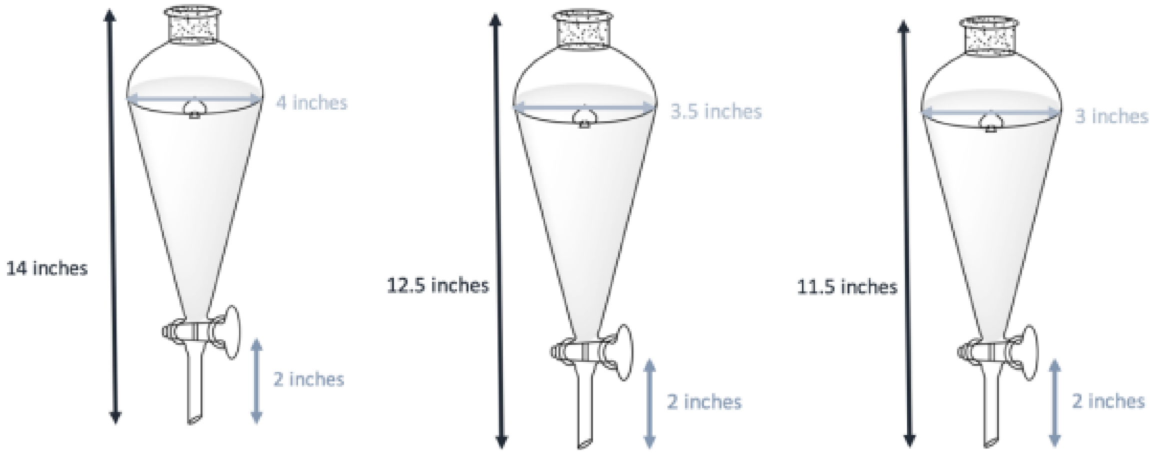


Figure 6: Three sizes of separatory funnels [4]

Living things that would need to be considered include:

- The eight graduate students and one undergraduate volunteer researching in the lab. At most, five people are in the lab at one time.
- The lab supervisor, Professor Helen Tran [6]

Additionally, the following are virtual aspects of the environment:

- University of Toronto wifi [6]
- Electrical system voltage is 120 V [8].

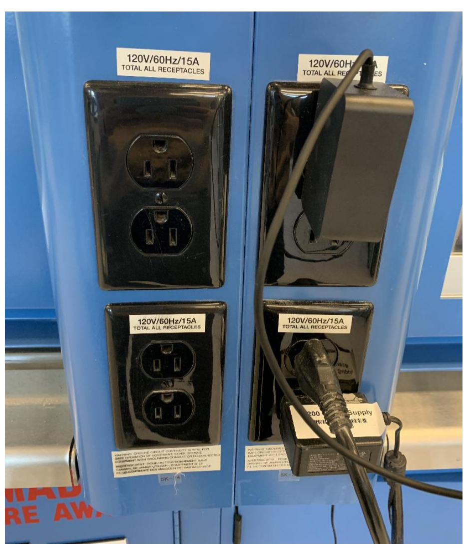


Figure 7: Electrical system voltage [4]

4.0 Stakeholders

The following table describes important stakeholders that would be interested in the redesign of the storage system.

Table 1. Stakeholders of this project and their interests.

Stakeholder Group	**Stakeholder Interest and Examples**
Laboratory Scientists [9]	Lab scientists in the applied science and/or research science fields use separatory funnels with liquid-liquid extractions. They will be a key stakeholder as storing away the funnels and other chemical materials are part of their routine procedures. Examples: Wet Lab Scientists [10], Materials Scientists, Chemists, Chemistry Start-Ups
Non-Governmental Organizations (NGOs)	NGOs deal with safe chemical usage and sustainable materials. They are interested in how different lab equipment is stored post-use, and will be concerned with what materials the storage solution will be made out of regarding its sustainability. Examples: BizNGO [11], Greenpeace
Government Organizations and Large Corporations [12]	Large corporations and government organizations dealing with fuel and hydro will be stakeholders, since separatory funnels are used for liquid-liquid extractions. Minimizing the cost to repair damaged separatory funnels are key to profiting organizations, so an efficient and safe storage space will be a part of their accounting cycle. Examples: Toronto Hydro, HydroOne, Suncor Energy, Enbridge [13]
Unions	Unions representing workers in chemical labs who deal with separatory funnels are concerned with the safety of these people. Unions will want the storage systems to be safe, properly maintained and non-hazardous to its members. Examples: CUPE, OHCU[14], OPSEU [15]

5.0 Detailed Requirements

The following sections will outline the technical elements required for a successful redesign of the storage unit for the separatory funnels. The functions, objectives and constraints will be considered to ensure an effective design, with metrics to ensure measurability of requirements.

5.1 Functions

The following primary and secondary functions were generated using the black box (Appendix A) and functional basis methods.

Primary Function:

- The design must store the equipment in the lab drawer such that the equipment is not damaged.

Secondary Functions:
- The design must organize the equipment in the drawer in a space-efficient manner.
- The design must allow equipment to be removed.
- The design must allow equipment to be added.

5.2 Objectives

The following objectives were generated using the how-why tree, with the ranking established by the pairwise comparison chart in Appendix B.

Table 2. The table explains the objective goals, metric and the justification.

Objective (the design should be:)	**Objective Goal**	**Metric**	**Explanation**
Able to reduce crack formation in glassware	Reduce crack formation by monitoring and maintaining low humidity levels.	Humidity levels should be between 30% to 50% [16]	Higher humidity levels contribute to crack formation and vary upon increasing humidity above 50% [16].
	Reduce movement of equipment.	Coefficient of friction between glass and material.	Larger coefficients of friction allow thermal energy to be generated instead of kinetic energy, which helps to reduce movement and collisions [20].
Cost effective (inexpensive)	Minimize costs used to build the design.	The material to build the design should be lower than the	When comparing design alternatives, the design with the least cost should be considered

		maintenance costs ($500) [17][18][5].	or the design with a cost less than $150 may be considered [17][18][5].
		Maintenance costs of all glassware (e.g. due to crack formation) should be less than $500[19][6].	The current cost to fix the funnels is at least $500, according to the client [6].
Easy to assemble	Maximise ease of building the design.	The design should use 1 part, available through commercial means. The design should take no time to assemble.	Client wants design to be as easy to build as possible. Industry standards include Design for Assembly [23].
Time efficient	Less time taken to put items and take items out of the system.	The time taken to operate the design should be between 5 to 10 seconds [6].	According to the client [6], the time taken to remove or add items should be around the current time it takes to add or remove items in the drawer.
Able to withstand mass	The design should be able to hold mass	The design should hold at least 9450 g (Appendix B.3) [19].	The design should be able to withstand the weight of the equipment (funnels).
Space efficient (allocate enough space for storing funnels)	Store the funnels in a way that more equipment may be stored within the drawer [4].	One third of the volume (25972cm^3, Appendix B.3) should be unoccupied for other equipment storage purposes [6].	The design should have sufficient space to operate and allow for more funnels to be stored.

5.3 Constraints

The following constraints stem from standards and guidelines, the materials used in the lab equipment, stakeholders, and other client restrictions.

Table 3. The constraints and metric and the clarifications of the relationship to the project.

Constraint: The design must…	**Metric / Description**	**Justification**
Follow University of	• Follow all standards about lab	University of Toronto has

Toronto Laboratory design standards and guidelines [21]	finishes and furnishings in Lab Safety Design Standards ● Surface and interior coatings are cleanable, non-absorbent, resistant to scratches, stains, moisture, chemicals, heat, shock, repeated decontamination.	a clear standard on laboratory furniture redesign that must be followed.
Not permanently change the drawer	● Dimensions are exactly the same as the current ones (5.5 x 19 x 45 inches) [4]. ● Power machinery cannot be used to alter the drawer [6]	The client does not allow a redesign of the entire drawer [6].
Effectively reduce the damage rate of the equipment	● The maintenance cost of the glassware must be less than $500 per year [6].	Current maintenance costs are $500 to $1000 annually [6].
Fit within the drawer	● Dimensions of the design must not be greater than dimensions of the drawer mentioned above [6].	It must operate within the drawer [6].

6.0 Idea Generation, Selection and Description of Alternative Designs

The following sections outline the methods used by the design team in the idea generation and selection phase to determine the three alternative design solutions.

6.1 Idea Generation

Idea generation explores potential solutions. In this case, the potential solutions generated pertained to storing funnels such that the funnels do not fracture. In order to expand the design space and generate a variety of ideas, several creativity methods are used.

- Free brainstorming combined with blue sky thinking allowed for a broader range of ideas. During structured brainstorming with the team, each member shared and gathered their ideas after 10 minutes. Furthermore, SCAMPER, magic solutions, working from first principles, benchmarking, and biological analogies allowed for more perspectives to be considered (Appendix C).
- Morphological charts enabled a combination design to be considered by associating a different sub function with a different method of achieving that function (Appendix C). After discussing the means inside the morph chart, the team members contributed about 10-15 ideas each.

The recurring themes when solving the problem were protection systems, soft cushioning, and storage containers.

6.2 Idea Selection Process

This section outlines the different methods and steps the design team took to select the top three idea lists, also outlined in Figure 5.

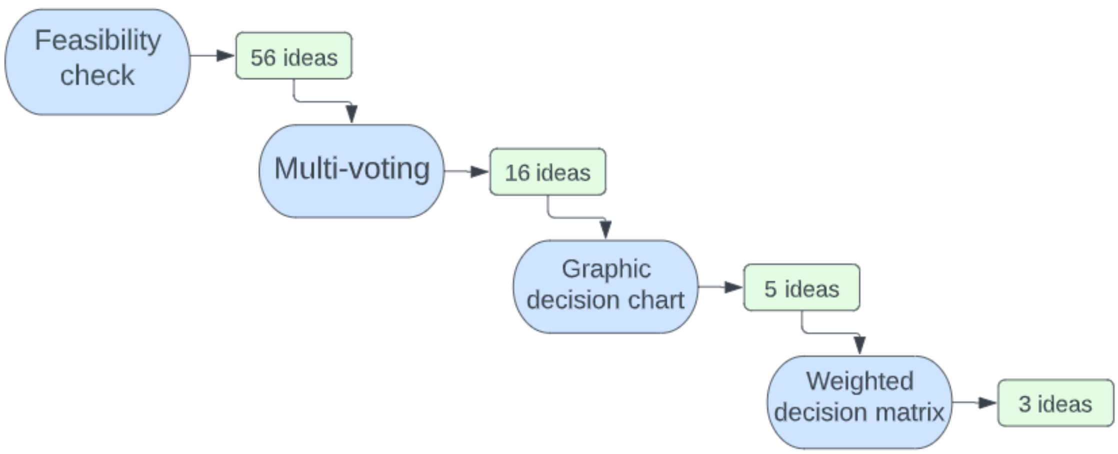


Figure 8: Flowchart of the idea selection process and steps taken

The process is listed below:

1. The team determined if the idea met the primary function and constraints through feasibility checks (Appendix D1).
2. Multi-voting was done (Appendix D2). Each team member had 12 votes to use during this step. 16 designs had at least two votes; these moved on.
3. A graphical decision chart (Figure 9) (Appendix D3) was used to rank ideas based on the top two objectives – safe and cost effective. Each member scored each idea on a scale of 1 (worst) to 4 (best) based on the objective criteria. The top five were selected, along with two ideas that received 6 votes from multi-voting, as they met other objectives well upon further inspection.
4. Among this list of seven ideas, some were very similar. These were combined to form the top five list.

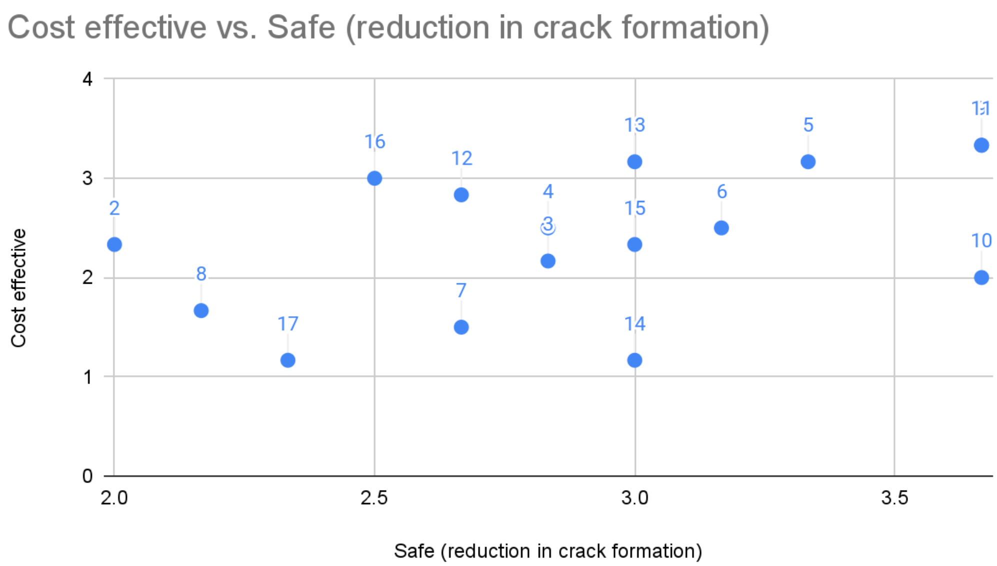


Figure 9: Graphical decision graph to compare the two highest ranked objectives and the design ideas. The numbers labelled correspond with the idea number found in Appendix D3.

5. A weighted decision chart (Appendix D4) was used to rank the remaining five ideas. Firstly, the importance of each objective was evaluated on a 100 point scale. Then each idea was evaluated based on the degree of satisfaction towards each objective, with a maximum of 100%. Finally, the two tables were merged, and the top three ideas entered the next step of evaluation.

The top 3 ideas were used in Alternative Design Specification where they were compared against the objectives.

6.3 Alternative Design Description

The following are descriptions of the three alternative design ideas that were selected after a weighted decision matrix, along with their performances against objectives:

6.3.1 Foam Base with Indents

Idea one consists of a layer of polyethylene foam settled on the bottom of the drawer, covering about half the height of the drawer (Figure 10). In the foam, there are funnel shaped cut-outs with 1” of extra space that prevent movement and provide cushioning. Various sizes of the indents allow for various sizes of equipment to be placed.

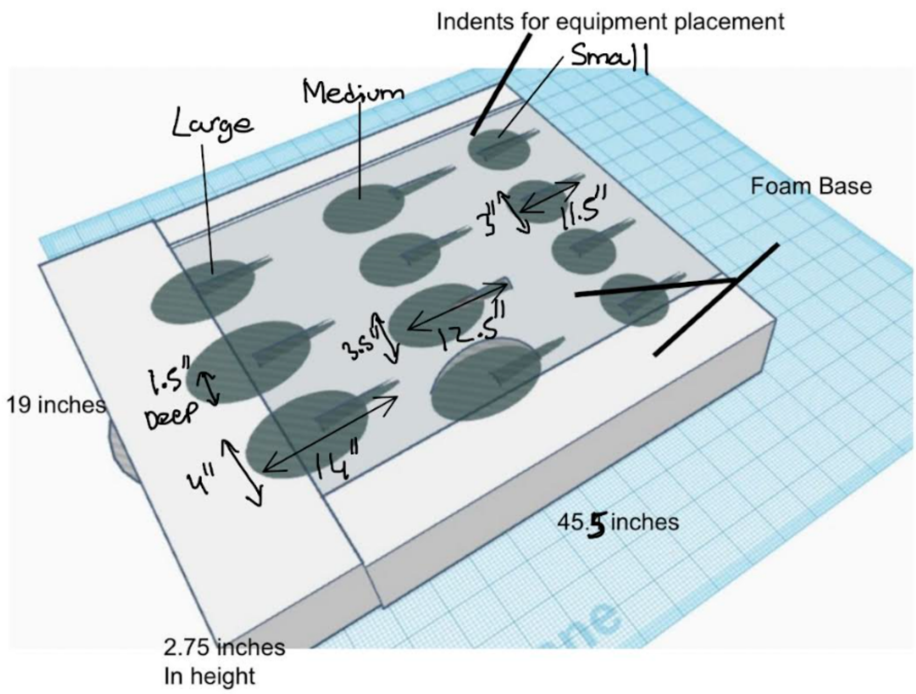


Figure 10. Foam base with indents.

Table 4: Objective performance for design 1.

Objective	Performance
Reduces crack formation	Coefficient of friction for polymer foams is ~0.463 [24]. No effect on humidity.
Cost effective	Moderately reduced annual glassware maintenance cost. Building cost ~$350 (Appendix E)
Easy to manufacture	Design only requires one part, available through commercial means. Time to assemble ~30 min, mostly for foam cutting (Appendix E)
Time efficient	User spends ~4 seconds (Appendix E)
Withstand weight	Design can hold ~737 kg. (Appendix E)
Space efficient	Design can hold 11 funnels (Figure 8).

6.3.2 PVC Pipes with 3-D Printed Rods

The second idea consists of a frame of PVC pipes. 3-D printed rods will be affixed to the sides to hold the funnels, and will be coated with rubber to mimic stands that hold funnels during experimentation.

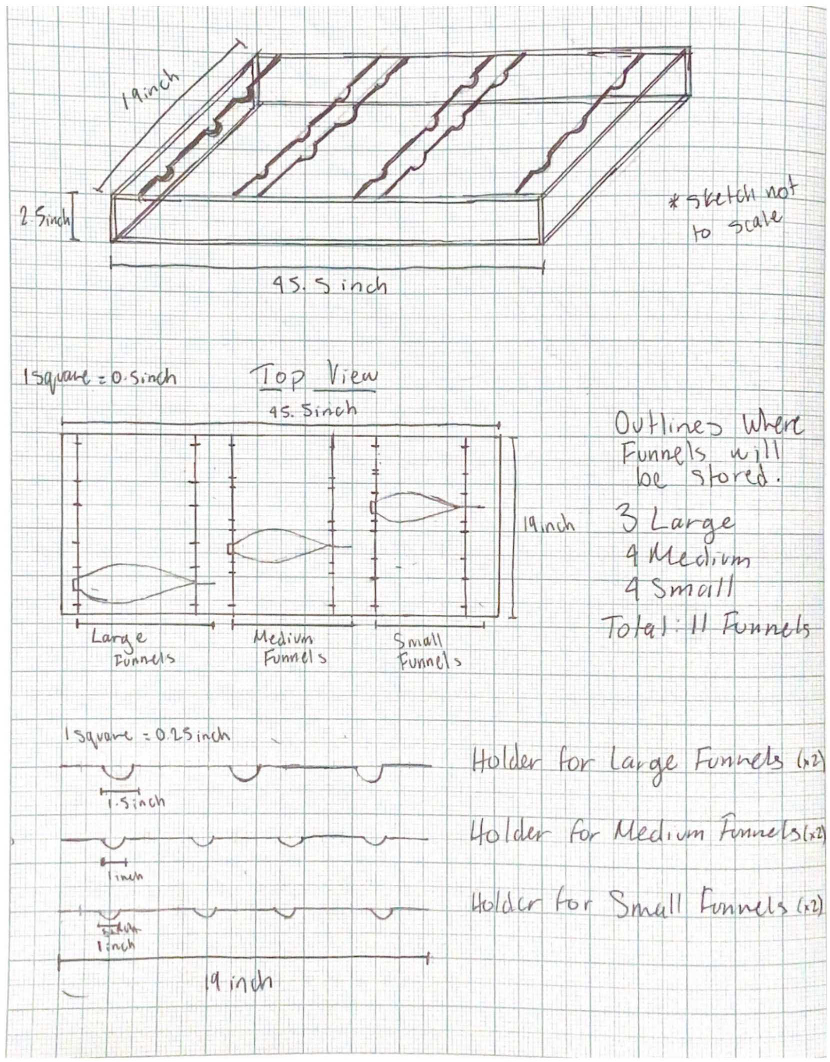


Figure 11. PVC Pipes with 3-D Printed Rods

Table 5: Objective performance for design 2.

Objective	Performance
Reduces crack formation	Coefficient of friction for rubber is ~0.6 [27]. No effect on humidity.

Cost effective	Highly reduced annual glassware maintenance cost. Building cost ~$80 (Appendix E)
Easy to manufacture	Design requires at least six 3-D printed rods, and a PVC pipe frame, which are available through commercial means. Time to assemble ~1.5 hours (Appendix E).
Time efficient	User spends ~5 seconds. (Appendix E)
Withstand weight	Design can hold ~1875 kg. (Appendix E)
Space efficient	Design can hold 11 funnels (Figure 8).

6.3.3 Styrofoam Base with Shock Absorbers

The final idea consists of a styrofoam lining the walls and base of the drawer. Wood dividers lined with polyethylene foam will separate the drawer into individual compartments where the funnels are stored.

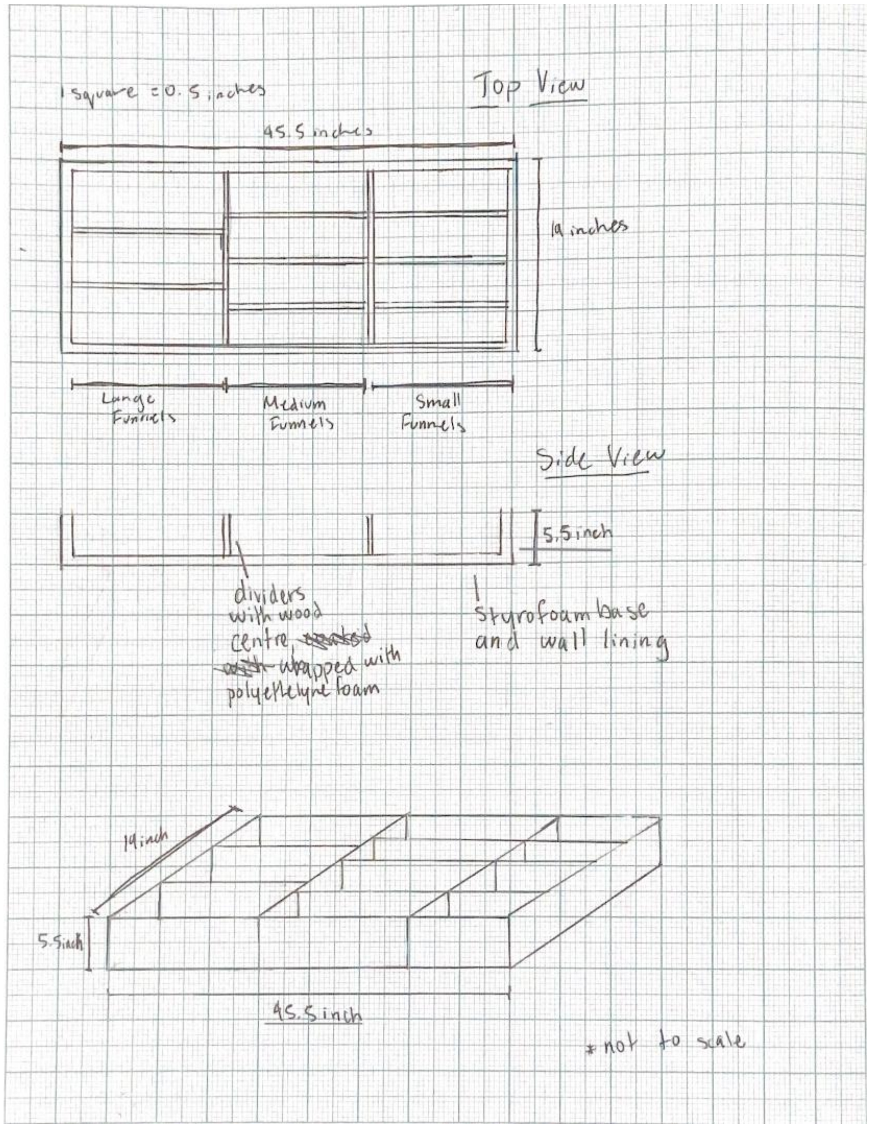


Figure 12. A styrofoam base with shock absorbers and compartments.

Table 6: Objective performance for design 3.

Objective	Performance
Reduces crack formation	Coefficient of friction for polystyrene is ~0.340 [24]. No effect on humidity.
Cost effective	Reduced annual glassware maintenance costs. Building cost ~$128 (Appendix E)
Easy to manufacture	Design requires foam base and additional parts to set up compartments, but these can all be found commercially. Time to build ~1

	hour. (Appendix E).
Time efficient	User spends ~4 seconds (Appendix E)
Withstand weight	Design can hold 5872 kg. (Appendix E)
Space efficient	Design can hold 11 funnels (Figure 9).

7.0 Proposed Conceptual Design Specification

The “Foam Base with Indents” design best suits the needs of the client, as it best fulfills the objectives because it received the most points from the Pugh method (Appendix D5). The client needs a design that prevents breakage in the stems and base of the separatory funnels. In this design, there are cut-outs for the funnels that prevent movement when opening the drawer, and these both provide cushioning and prevent movement, reducing the occurrence of breakage.

Furthermore, the design does not take any longer to use than a standard drawer, and implementing the design can be done with minimal construction ability, which is important to the client. Polyethylene foam is a strong material that is resistant to moisture and chemicals [33]. Polyethylene will last approximately ten years in typical indoor conditions, which satisfies a low build cost associated with creating or replacing the design [34]. Additionally, this material can be melted down and reused, which satisfies environmental concerns from NGO stakeholders [35].

The most important objective is to reduce the cost associated with repairing damaged funnels, and this design will reduce breakage significantly. This design will successfully decrease the breakage of funnels, while also being quick to use, relatively inexpensive compared to the current costs, and can be implemented without significant construction skills.

8.0 Measures of Success

The plan for this measure of success is to test the success of the proposed design. The test will consist of a styrofoam box the size of the drawer where the following tests will be conducted:

Table 7. Tests for measures of success and description.

Test	Description
Build Time	The user will be given a block of styrofoam and will have to carve out the shape of one large separatory funnel using tools such as an X-Acto knife. The test will be timed and then multiplied by 11. This test will determine how easy the design is to build [23].

Shake Test	A piece of styrofoam the size of the drawer used for testing will be provided with a cutout of a borosilicate separatory funnel. The funnel will be placed in the foam cutout. A motion sensor device will detect how much the funnel moves when the drawer is opened and closed. The test is repeated without the styrofoam base. The motion of the funnel in the drawer will be compared with the first result. If successful, the motion of the funnel in the styrofoam base will be less than the motion of it without. This will mean there will be less collisions, thus less funnels will crack.

9.0 Conclusion

The Conceptual Design Specification (CDS) identifies the problem of the crack formation on glassware equipment in the drawer from the project requirements. The CDS highlights the process in idea generation, idea selection, alternative design descriptions, a final proposed design, and details the measures of success. This resulted in top three alternative ideas including one proposed design: foam base with indents. As a next step, the design team will carry out the measures of success outlined to ensure the design will be successful.

10.0 References

[1] Abigail Clapperton. Project Description. Jan. 26, 2023.

[2] Le Gourriérec, C., Durand, B., Brajer, X. " Star Crack Formation via Low-Velocity Impact on Glass Windows," *J. dynamic behavior mater.* [Online]. Date Accessed: Mar 3, 2023. Available: https://link-springer-com.myaccess.library.utoronto.ca/article/10.1007/s40870-022-00351-w#Sec13

[3] "Most Common Types of Windshield Cracks," Nu Vision Auto Glass. [Online]. Date Accessed: Mar. 3, 2023. Available: https://www.nuvisionautoglass.com/most-common-types-of-windshield-cracks/

[4] Abigail Clapperton. Information PDF. [PDF].

[5] "Rotary Separatory Funnel Rack," Thomas Scientific. [Online]. Date Accessed: Feb. 16, 2023. Available: https://www.thomassci.com/Laboratory-Supplies/Racks/_/Rotary-Separatory-Funnel-Rack

[6] Abigail Clapperton. Client Meeting 1. Feb. 6, 2023.

[7] Weaver, J.L., DePriest, P.T., Plymale, A.E. "Microbial interactions with silicate glasses," [Online] Date Accessed: Mar. 3, 2023. Available: https://www.nature.com/articles/s41529-021-00153-w

[8] University of Toronto. "Electrical Design Standard," [PDF]. Date Accessed: Mar. 3, 2023. Available: https://www.fs.utoronto.ca/wp-content/uploads/2022/07/Electrical-Design-Standard-Rev-01-2022-07-15.pdf

[9] "Separatory Funnels," Fischer Sci. [Online]. Date Accessed: Feb. 12, 2023. Available: https://www.fishersci.com/us/en/browse/90094210/separatory-funnels?page=1

[10] Government of Newfoundland and Labrador, "Laboratories for Water Quality Analysis," Environment and Climate Change, 2022. https://www.gov.nl.ca/ecc/waterres/quality/labs/ (accessed Mar. 03, 2023).

[11] "BizNGO for Safer Chemicals & Sustainable Materials," BizNGO. [Online]. Date Accessed: Feb. 12, 2023. Available: https://www.bizngo.org/

[12] "Separating Funnel - Working Principle and Uses," Master Chemistry. [Online]. Date Accessed: Feb. 12, 2023. Available: https://themasterchemistry.com/separating-funnel-principle-and-uses/

[13] J. W. Carpenter, “The 7 Biggest Canadian Energy Companies (IMO.TO, TRP),” Investopedia, Apr. 29, 2022.
https://www.investopedia.com/articles/markets/091115/7-biggest-canadian-energy-companies.asp

[14] “Ontario Council of Hospital Unions,” OCHU. [Online]. Date Accessed: Feb. 12, 2023. Available: https://ochu.on.ca/

[15] E. and S. D. Canada, “Labour organizations in Canada - Organization,” www.canada.ca, Jul. 09, 2013.
https://www.canada.ca/en/employment-social-development/services/collective-bargaining-data/labour-organizations.html

[16] C. Brokmann, S. Kolling, and J. Schneider, “Subcritical crack growth parameters in glass as a function of environmental conditions”, link.springer.com, Sep. 27, 2020. [Online]. Date Accessed: Feb. 12, 2023. Available:
https://link.springer.com/article/10.1007/s40940-020-00134-6.

[17] “Materials Used in Drawer Systems,” Trekboxx. [Online]. Date Accessed: Feb. 12, 2023. Available: https://www.trekboxx.com/materials-used-in-drawer-systems

[18] “Hillman 12-in W x 18-in L Hot Dipped Galvanized Steel Solid Sheet Metal,” Lowes. [Online]. Date Accessed: Feb. 12, 2023.
Available:https://www.lowes.ca/product/sheet-metal/hillman-12-in-w-x-18-in-l-hot-dipped-galvanized-steel-solid-sheet-metal-44487

[19] M. Bauccio, “Borosilicate Glass,” Borosilicate glass. [Online]. Date Accessed: Mar 03 ,2023. Available:
https://www.matweb.com/search/DataSheet.aspx?MatGUID=b0dbbac859444ffe98307f24ffd4c6a2.

[20] “Work done by friction during a complete inelastic collision,” Journal of Physics: Conference Series. [Online]. Date Accessed: March 21, 2023. Available:
https://iopscience.iop.org/article/10.1088/1742-6596/134/1/012035/pdf

[21] Office of Environmental Health & Safety, University of Toronto, Version 2.0, “LABORATORY DESIGN STANDARD AND GUIDELINES,” December 2018. [Online]. Date Accessed: Feb. 10, 2023. Available:
https://ehs.utoronto.ca/wp-content/uploads/2018/12/Lab-Safety-Design-Standard-December_2018.pdf

[22] “Lab Equipment,” Chemistry LibreTexts. [Online]. Date Accessed: Feb. 11, 2023. Available:
https://chem.libretexts.org/Courses/Hope_College/General_Chemistry_Labs/Lab_Equipment

[23] Velling, Andreas, "Design for Assembly," Fractory. [Online]. Date Accessed: March 21, 2023. Available: https://fractory.com/design-for-assembly-dfa/

[24] "MatWeb - Material Property Data," MatWeb. [Online]. Date Accessed: March 21, 2023. Available: https://www.matweb.com/index.aspx

[25] "Universal Science EV - UniFoam," Materials Direct. [Online]. Date Accessed: March 21, 2023. Available: https://materials-direct.com/product/universal-science-ev-unifoam-ht80-65mm/

[26] "Custom drawer inserts - how long do they take," ShadowFoam. [Online]. Date Accessed: March 21, 2023. Available: https://www.shadowfoam.com/how-long-does-it-take-to-cut-shadow-foam-drawer-inserts/

[27] Tuononen, Ari, "Onset of frictional sliding of rubber-glass contact under dry and lubricated conditions," Nature. [Online]. Date Accessed: March 21, 2023. Available: https://www.nature.com/articles/srep27951

[28] "What is Cyanoacrylate (Super Glue) & How Does It Work?" Copeland. [Online]. Date Accessed: March 21, 2023. Available: https://mtcopeland.com/blog/what-is-cyanoacrylate-super-glue-and-how-does-it-work/

[29] "PVC Pipe," Home Depot. [Online]. Date Accessed: March 21, 2023. Available: https://www.homedepot.ca/en/home/categories/building-materials/plumbing/pipe-and-fittings/pvc-pipes-and-fittings/pvc-pipe.html

[30] "3D Printing in the Robarts Digital Studio," University of Toronto Libraries. [Online]. Date Accessed: March 21, 2023. Available: https://onesearch.library.utoronto.ca/faq/3d-printing-robarts-digital-studio

[31] "Construction Foam Block," Hot Wire Foam Factory. [Online]. Date Accessed. March 21, 2023. Available: https://hotwirefoamfactory.com/036B-constructFoamBlock.html

[32] "Optix Clear Acrylic Sheet," Home Depot. [Online]. Date Accessed: March 21, 2023. Available: https://www.homedepot.ca/product/optix-clear-acrylic-sheet-080-inch-x-18-inch-x-24-inch/1000126291

[33] "Polyethylene Foam," Foam Factory. [Online]. Date Accessed: March 21, 2023. Available: https://canada.foambymail.com/polyethylene-foam.html

[34] "Life Expectancy of Polyethylene Insulation Products," Nomaco. [Online]. Date Accessed: March 21, 2023. Available: https://www.nomaco.com/wp-content/uploads/2016/04/TA42.pdf

[35] "Which Plastics are Recyclable in Canada," Bale Force. [Online]. Date Accessed: March 21, 2023. Available: https://baleforce.com/plastic-numbers-canada/

Appendix A: ***Function Identification***

Table 8. The black box method elucidates the flow of mass, energy, and information in a system as the system input and output; this process enables the function generation.

Input		**Output**
Mass Various equipment but to fit the client's need the separatory funnel will be the priority. As a general approach of storage in laboratory drawers: ● erlenmeyer or volumetric flasks, graduated cylinders ● beaker/ pipette/ burettes ● various stands or clamps ● test tubes [22]	**← Design →**	**Mass** Various equipment but to fit the client's need the separatory funnel may be the priority. The funnels must remain without cracks.
Information The user may have the information that they are using the design and/or how they operate the design.		**Information** The user may visually see if there are any cracks in the equipment.
Energy Mechanical energy required to operate the design. Possibly the kinetic energy of the moving separatory funnels.		**Energy** Potential energy of the separatory funnels that are not moving.

Appendix B: ***Objectives***

B.1 How-Why Chart

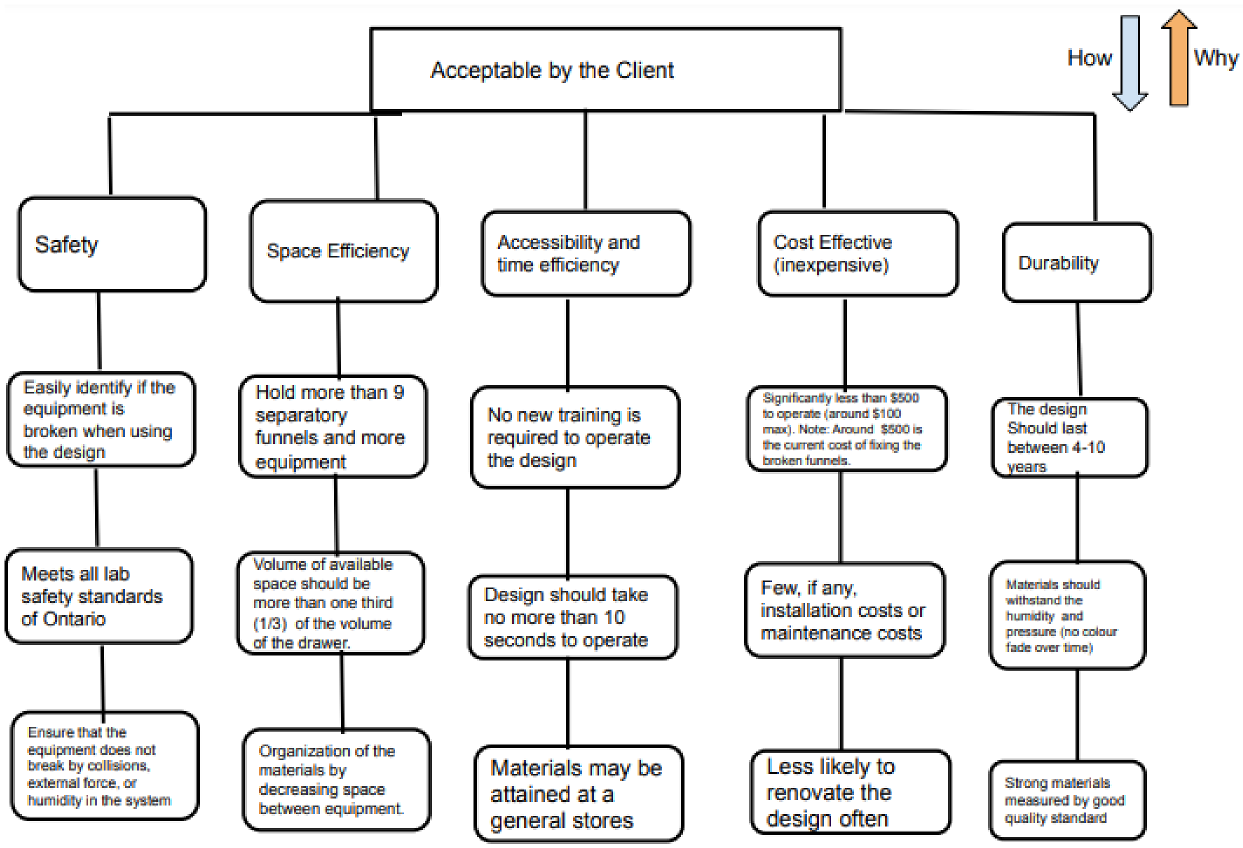


Figure 13. To fulfill the client's need, a how-why chart illustrates the generation of possible objectives; when moving down the chart, answers to how the design incorporates the objective goals are found and why these objectives are chosen are depicted by moving upwards in the chart.

B.2 Pairwise Comparison

The client considers aesthetics as least important, space and time efficiency slightly more, and safety as the most important factor. As a result, when conducting the pairwise comparison with the team consensus, two objective goals are valued amongst each other. In each row, the objective goal with the highest total score is ranked higher when considering the design. For instance, between cost versus space efficiency: team discussions explain how approximately one third of the space remains unused in the drawers, which means more work may be done to improve the cost.

Table 9. Pairwise comparison chart depicts the ranking of objectives from the total score.

Objective	**Safety**	**Space Efficiency**	**Time efficiency**	**Cost Effective**	**Durability**	**Easy to Assemble**	**Total Score**

Safety	x	1	1	1	1	1	5
Space Efficiency	0	x	0	0	0	0	0
Accessibility and Time efficiency	0	1	x	0	1	0	2
Cost Effective (inexpensive)	0	1	1	x	1	1	4
Durability	0	1	0	0	x	0	1
Easy to Assemble	0	1	1	0	1	x	3

It is important to note that safety is defined as the metric from the objectives chart. Similarly, a score of zero does not indicate that the objective is not valuable to the project; the score is a reference point to compare with other objectives. Each of the objective goals are considered with a percent weighted factor when evaluating the design in future reports.

The ranking of the objective goals is as follows:

1. Safety
2. Cost Effective (inexpensive)
3. Accessibility and time efficiency (time it takes to reach or use the design)
4. Durability
5. Space Efficiency

B.3 Research and Metric of the Objectives

What is the volume of the separatory funnels?

The approximate volume (estimated as a cylinder) of the funnels are as follows:
Large funnels: $2883 cm^3$
Medium funnels: $1970 cm^3$
Small funnel: $1332\ cm^3$

The dimensions of the current drawer are 5.5 in x 19 in x 45.5 in = 4754.75 cubed inches

= 77916.39 cm cubed. [4]

The dimensions were provided by the client [4]

Note: the uncertainty in the calculation may vary depending on the type of instrument used and the precision of the scale used to measure the dimensions.

How much kinetic energy and work is needed to operate the design?

Using the upper bound as a safe side strategy, the user should not expend more than the kinetic energy required to move 4kg of a box at a velocity of 1m/s (2J of kinetic energy); the work of using about 22.5 N (between 20 N and 25 N [16]) of force to be pushed across 0.5meters (approximately 19 inches from the dimensions given) should be no more than 11.25 J.

kinetic energy = ½ (m)(v^2)

Work = force x displacement

The cost:

- Depends on the design type: 3D printing rates may vary
- should be less than $500 because it is about the cost it takes to repair or replace the separatory funnels, as mentioned in the client meeting

How much does a typical separatory funnel made of Borosilicate Glass weigh?

The density of the glass is 2.40g/cc [19] and the volume of the glass is found from the volume of the cone (4pi(r)^2 *(h/3)) where the radius is 5.08 cm, and the height is 30.48cm for the larger funnel. After accounting for the thickness of the glass and the empty area,the mass is as follows: [6]

About 315 grams

Since there are more than nine separatory funnels that should be stored, an upper estimate may be 12 separatory funnels multiplied by a safety factor of 2.5.

2.5((12(315)) = 9450g is the load that the design should be able to hold

What is the main material used to create the drawer? This will be used to benchmark it to the cost of the project.

Galvanized sheet metal [17].

How much does this material cost?

The material costs $14.50 with a 12 inch by 18 inch sheet of metal [19].

However, according to the dimensions of the project, there may be alterations of the given sheet of metal that may be required and the price may vary in a slight range depending on the size, and the store. Therefore:

$14.50 x 5 = $72.75 (5 sides of the drawer with the top side not requiring the material)

Multiplying this by a safety factor of 2 : the overestimate of the total cost of the materials about $150 (rounding).

Appendix C: *Idea Generation*

Idea Generation

Brainstorming

1. foam compartment
2. single grid
3. spring buffer
4. Foam Sleeves
5. rubber boot
6. Build a step-like shelf with non-slip thin pipes
7. Mini stands to hold funnels in drawers (maybe sideways)
8. Some kind of addition to funnel to prevent breakage
9. Suspended in some type of liquid or fluid to keep them in place?
10. Mini forge inside drawer to repair glassware
11. Like the dishwasher stand things (but sideways)
12. Elastic bands (that can be removed) to hold funnels in place
13. Small pieces of fabric & rope with securable pieces
14. Something that changes volume on the end once thing is attached?
15. Plastic wrap or similar material on top to prevent movement
16. Vacuum or suction to prevent movement
17. Soft pouches
18. Cutouts to hold funnels
19. Stem attachment
20. Sensors for opening or closing the drawer (maintain force) and a digital monitor showing number of items and humidity
21. Sponge like containers that are of exact dimensions of funnels that are half open
22. Rough surface to prevent movement of funnels in drawer
23. Sponge or cloth-like part on the top of the drawer's edge.
24. Funnels stored in cube like organization

25. Triangular format and flat stacking racks on top of each funnel (bottom part must take in larger and end up smaller at the top) inside drawer
26. Organizer broken into compartments for different sizes
27. Organizer with notches to hold funnel in
28. cushioning/foam/ etc on side of walls
29. Seat belts
30. claws to hold in place
31. gel/tape
32. Adjustable storage system/change size/shape of storage units
33. Compartments with holes
34. Something that morphs into shape of equipment
35. safe/locked compartment
36. Silicon molds
37. Machine that blasts air & can suspend equipment in place
38. Silicon gel
39. Wooden frames
40. gel-Like materials
41. Towels/clothes
42. Paper barriers
43. Metallic barriers
44. Filing cabinet type
45. Robotic arms mechanized to carefully open/close drawer
46. mass/spring system

SCAMPER process

Substitute
- Feathers instead of foam
- Pom pom balls instead of foam
- Pillows instead of foam
- Yarn / string
- Play-Doh (modelling clay)
- Marshmallows
- Cotton Balls
- Candle wax
- Carpet
- Leaves (moist)
- Parchment paper
- Butter
- Seeds

- sand
- Layered compartments (more than funnels)
- Slime
- Non-slip surface
- Materials for design: wood frame, metal frame, plastic/3D printed frame, frame entirely made of cushioned material

Combine
- cushioning with frame
- Different types of cushioning
- Smaller compartments with cushioning in the drawer
- Layered compartments stacked on top with a soft cloth in between
- A rack that goes through the center of the drawer, and funnels may be stored upon them
- Have a humidity controller onto the storage container within the drawer
- storage technique where multiple raised rectangular platforms are placed parallel at an angle. Between the raised platforms, the equipment may be stored vertically. This may be used for half of the drawer and the other half, layered compartments are used.

Adapt (modify,minify, magnify)
- long thin rectangular compartments
- large wide triangular or rectangular compartments
- large, small cotton balls covering equipment and preventing collisions
- Smaller boxes, made of wood, within the drawer

Put to other use
Focus: storage
- Pencil case is also a storage
- cans
- cardboard boxes
- suitcase
- bags
- wallets
- locker

Focus: protection (from breakage)
- net-like protection (spider web design type)
- Glass that can withstand a high amount of weight and pressure

Focus: organization
- Labels (paper or digital)

Eliminate
- Eliminate compartments and just store funnels in a common drawer

Rearrange
- Locked semi-circular compartments with each equipment encapsulated within
- Equipment stored in vertical racks (for the first half of the drawer) and horizontal racks for the other half of the drawer
- Organization with the size of arrangement: smaller compartments for smaller equipments

Magic Solutions
- Modify humidity levels to prevent cracks
- Automatically convert kinetic energy of moving equipment to potential energy (energy absorber)

Biomimicry
- Encapsulate every equipment by the material (cushion) : seeds are encapsulated and well protected
- In the enzyme reaction process, specifically the induced fit model of substrate and enzyme reaction: when an equipment is placed into the drawer, the equipment fits into the polymeric stand and is secured in place.
- Nest is built for protection: in the drawer, multiple semi-spherical soft compartments are arranged. To prevent them from moving into each other when the drawer is opened or closed, these semi-spherical containers are secured in place by a plastic base.These semi spherical compartments automatically close
- Flower bud closure: the shape of the flower bud may be used as a case for storing fragile equipment

Morphological Chart:
The morphological chart is used to generate several ideas and expand the design space. An example of each idea generated would satisfy the functions or sub functions from the project requirements. The means in the table illustrates a potential solution to how a specific sub function or function is achieved.

Table 10. Examples of combinations of ideas are found from connecting the subfunction with each separate means.

Sub functions	**means**	**means**	**means**	**means**	**means**	**means**	**means**

Protect equipment (prevent movement of funnels)	Styrofoam holder	Ethafoam material supporting the funnels	rubber boot or rubber material for protection around the funnels	pouches that are waterproof and anti-bacterial	display and control humidity levels	shock absorbing materials (types of polymers)	Stands that lock the equipment in place and Rough surface to prevent movement of funnels in drawer
organize the equipment/ mass and information	rectangular compartments	frames with notches to hold equipment	triangular compartments	adjustable compartments or racks	Design contains vertically divided up sections	large compartment contains a smaller compartment within	Raised platforms (equipment stored in the middle of the platforms)
allow equipment to be removed or added	claws	open from the top of the design	materials/containers that fit equipment exactly (mold/specific holes)	stands	Shell or cave like shape of the design (open from the sides)	Design detaches itself through detection/sensors	Design with the drawer is not enclosed from all the sides

Combination of ideas from the morph chart:

- Styrofoam holder with frames and stands that have notches to hold the equipment.
- strofoam holder with rectangular compartments and claws to hold the funnels in place
- rubber boot with triangular compartment stands
- Ethafoam material used in the design with containers placed on adjustable compartments/racks
- pouches that are waterproof and anti-bacterial has layered compartments that are open from the top
- Foam sleeves with removable elastic bands running throughout the drawer
- Rectangular components with a removable plastic wrap on top
- Funnels stored in pencil-case-like pouches that can be labeled and zipped up , stored in foam indents
- Base of foam / carpet with holes similar to bottom half of funnel where they can be stored
- Large pole with extendable / closeable claws to keep funnels in place
- Foam base with silicone molds to hold funnels in, with humidity controlling device
- Suction devices that can be turned on / off to keep funnels in place with a cushioned base
- Metallic barriers that you can just take things out of with labels to communicate type of equipment / size

- Sideways dishwasher stands with cushioning and labels
- A small, thin piece of fabric with with inflatable valve on end and stands to hold ends of funnels
- Laminated paper barriers with labels and foam / styrofoam base with indents
- Labeled foam pouches that can be opened / closed to store funnels in (no other additions)
- Double-sided claw that can be attached to the funnel stem (or equipment base) and to a storage rack
- Ethafoam material supporting the funnels divided into triangular compartments with shell or cave like shape of the design (open from the sides)
- shock absorbing materials (types of polymers) with frames to hold equipment in a vertical position
- Ethafoam material supporting the funnel; the design uses the shape of the flower bud may be used as a case for storing fragile equipment. The design can open and close automatically when users attempt to open it (by sensors)
- Velcro-like material attached on the equipment's side and the interior of the design
- Design contains vertically divided up sections and humidity levels are controlled; design detaches itself through detection/sensors
- adjustable compartments or racks combined with net-like protection (spider web design)
- Claws that open and close(allow equipment to be stored/removed) and made of ethafoam material
- pouches that are waterproof and anti-bacterial combined with rectangular compartments
- Stands that lock the equipment in place are placed in each of the small rectangular compartments
- rubber material for protection around the funnels with semi-circular compartments with each equipment encapsulated within
- Shell shape of the design with styrofoam holders; this is similar to the storage of cups
- Sensors for opening or closing the drawer (maintain force) and a digital monitor showing number of items and humidity combined with a rough surface at the bottom of the design to prevent movement of funnels; there are vertical dividers between the equipment
- Raised platforms (equipment stored in the middle of the platforms) and vertical dividers between sections made with ethafoam material
- Metal frame with rods parallel to width of drawer. Rods are separated about the length of a funnel apart. indents/notches are in the rods to hold the funnels. Rods coated with rubber similar to stands that hold funnels during experimentation. Funnels can be stores in alternating directions
- Similar to above, but use push and release locks to secure funnels in place
- Similar to above, but instead of a full frame, there are only sections (two rods, distance of separatory funnel apart with dents)
- Similar to first idea, with adjustable lengths for other drawers
- Line sides of the drawer with polyethylene foam / have compartments lines with

polyethylene foam
- Many layers of polyethylene foam stacked together with holes for funnels carved out
- IKEA summera drawer insert inspired → sections outlines by lifts in the mat, prevents rolling
- Triangular storage units size of the largest separatory funnel, lined with polyethylene foam
- Stands attached to bottom of drawer where separatory funnels can be placed (independent of size of drawer)
- Mat with stands where funnels can be stored (dependant on size of drawer)
- Individual plastic compartments the same size of large funnel (14 x 4 inch)
- Polyester stuffing. That's it. And then u put the funnels in the drawer
- Styrofoam stands which compartmentalize the different separatory funnels to its own size
- Styrofoam base, shock absorbing material lining against walls, wood/metallic bases to prevent bumping into one another
- Large compartment with smaller compartments inside which has a shell around each smaller compartment, every funnel is completely separate from one another due to the shells, with a styrofoam base layer
- Ethafoam shaped specifically to the design which is used as a pouch, then placed on stands
- Circulator rubber pouches which roll around but still protect the separatory funnels during collisions, with shock absorbing materials on the walls and a ethafoam base layer
- Pouches which drop down from the stands to fit in the funnels
- Claws attached to the walls of drawer which secure all funnels in place
- Secured clamps for each funnel which is lined with ethafoam on its clamp ends to minimize movement
- Styrofoam mold with compartments and a lid to cover them
- Rubber slot angled down with a drain to let any excess water, chemicals drain into a receptacle
- Use tubes wrapped in rubber boots to build stairs that overlap left, right, up and down
- Wrap the drawer with styrofoam and divide the drawer into triangular-shaped tiers with styrofoam compartment
- The entire drawer is covered with rubber, and there are small grooves customized according to different sizes on the surface to fix equipment

Appendix D: Idea Selection Process

D1. Feasibility check

Feasibility checks compare each idea to the primary functions and constraints and checks if the design idea meets them. Ideas that do not meet the primary functions and constraints are eliminated, and those that pass the feasibility check enter the next step of selection. We had 56 ideas that passed the feasibility check.

Table 11: Feasibility Checks

	Does it pass the feasibility checks? (e.g. meets all functions and constraints)?	**If no, explain why here**
Ideas:		
foam compartment	yes	
single grid	yes	
spring buffer	yes	
Foam Sleeves	yes	
rubber boot	yes	
Build a step-like shelf with non-slip thin pipes	yes	
Mini stands to hold funnels in drawers (maybe sideways)	yes	
Some kind of addition to funnel to prevent breakage (e.g. shock absorbing sleeve)		not specific enough
Suspended in some type of liquid or fluid to keep them in place?	no	Does not meet the U of T lab guidelines
Mini forge inside drawer to repair glassware	no	Would not fit within the dimensions of the drawer
Like the dishwasher stand things (but sideways)	yes	
Elastic bands (that can be removed) to hold funnels in place	yes	
Small pieces of fabric & rope with securable pieces	yes	
Pneumatic / hydraulic system that changes volume on the end once something is attached?	yes	
Plastic wrap or similar material on top to prevent movement	maybe	would need to be resistant to scratches

Vacuum or suction to prevent movement	yes/no	vacuum no (would require permanent alterations to drawer), suction yes
Soft pouches	yes	
Cutouts to hold funnels	yes	material dependant
Stem attachment		not specific enough
Sensors for opening or closing the drawer (maintain force) and a digital monitor showing number of items and humidity	yes	
Sponge like containers that are of exact dimensions of funnels that are half open	maybe	material dependant (probably not sponges, as they can absorb liquids)
Rough surface (e.g. creates friction) to prevent movement of funnels in drawer	yes	combine with something else
Sponge or cloth-like part on the top of the drawer's edge.	maybe	
Funnels stored in cube like organization	yes	
Triangular format and flat stacking racks on top of each funnel (bottom part must take in larger and end up smaller at the top) inside drawer	yes	
Organizer broken into compartments for different sizes	yes	
Organizer with notches to hold funnel in	yes	
cushioning/foam/ etc on side of walls	maybe	material dependant
Seat belts	maybe	
claws to hold in place	yes	
gel/tape	no	gel has moisture (against constraints)
Adjustable storage system/change size/shape of storage units	yes	
Something that morphs into shape of equipment	maybe	material dependant
safe/locked compartment	yes	
Silicon molds	yes	

Machine that blasts air & can suspend equipment in place	no	Would not fit within dimensions of drawer, or would require permanent deformation of drawer
Silicon gel	yes	
Wooden frames	yes	
gym flooring	yes	
Towels/cloths	no	takes in moisture (absorbs)
Paper barriers	maybe	would likely have to be laminated so it would not absorb liquids
Metallic barriers	yes	
Filing cabinet type	yes	
Robotic arms mechanized to carefully open/close drawer	yes	
mass/spring system	yes	
Scamper		
Substitute		
Feathers instead of foam	no	takes in moisture
Pom pom balls instead of foam	no	takes in moisture
Pillows instead of foam	maybe	
Yarn / string	no	takes in moisture
Play-Doh (modelling clay)	no	takes in moisture
Marshmallows	no	takes in moisture
Cotton Balls	no	takes in moisture
Candle wax	maybe	
Carpet	yes	
Leaves (moist)	no	takes in moisture
Parchment paper	yes	
Butter	no	takes in moisture
Seeds	no	takes in moisture
sand	no	takes in moisture

Slime	no	takes in moisture
Non-slip surface	yes	
Materials for design: wood frame, metal frame, plastic/3D printed frame, frame entirely made of cushioned material	yes	
Combine		
cushioning with frame	yes	
Different types of cushioning	not specific	
Smaller compartments with cushioning in the drawer	yes	
Layered compartments stacked on top with a soft cloth in between	maybe	cloth can not be moisture absorbent
A rack that goes through the center of the drawer, and funnels may be stored upon them	yes	
Have a humidity controller onto the storage container within the drawer	yes	
storage technique where multiple raised rectangular platforms are placed parallel at an angle. Between the raised platforms, the equipment may be stored vertically. This may be used for half of the drawer and the other half, layered compartments are used.	yes	
Adapt (modify,minify, magnify)		
long thin rectangular compartments	yes	must meet separatory funnel sizes
large wide triangular or rectangular compartments	yes	
large, small cotton balls covering equipment and preventing collisions	no	moisture, but other material (substitution) may work
Smaller boxes, made of wood, within the drawer	yes	
Put to other use		
Focus: storage		
Pencil case is also a storage	yes	

cans	yes	
cardboard boxes	no	takes in moisture
suitcase	yes	
bags	yes	
large wallets	no, probably	used more for flat items, such as cards, so could increase glass repair costs
locker	yes	
Focus: protection (from breakage)		
net-like protection (spider web design type)	yes	
Glass that surrounds equipment can withstand a high amount of weight and pressure	yes	
Eliminate		
Eliminate compartments and just store funnels in a common drawer	no	would likely increase glass repair costs, as this is the current solution but without any protection (bubble wrap & cloth)
Rearrange		
Locked semi-circular compartments with each equipment encapsulated within	yes	
Equipment stored in vertical racks (for the first half of the drawer) and horizontal racks for the other half of the drawer	yes	
Organization with the size of arrangement: smaller compartments for smaller equipments	yes	
Magic Solutions		
Modify humidity levels to prevent cracks	maybe	needs system that may not fit in the drawer
Automatically convert kinetic energy of moving equipment to potential energy (energy/shock absorber)	maybe	shock absorbing materials could work
Biomimicry		

Encapsulate every equipment by the material (cushion) : seeds are encapsulated and well protected	yes	
In the enzyme reaction process, specifically the induced fit model of substrate and enzyme reaction: when an equipment is placed into the drawer, the equipment fits into the polymeric stand and is secured in place.	yes	
Nest is built for protection: in the drawer, multiple semi-spherical soft compartments are arranged. To prevent them from moving into each other when the drawer is opened or closed, these semi-spherical containers are secured in place by a plastic base.These semi spherical compartments automatically close	yes	
Flower bud closure: the shape of the flower bud may be used as a case for storing fragile equipment	yes	

D2. Multi-voting

In a multi-voting process, each team member has 12 votes to choose their favorite design. 25 ideas were voted on and 16 ideas had at least 2 to move forward.

Table 12. Multi-voting process

Combination of ideas from the morph chart:	Augustin	Prantika	Siaa	Sam	Tyler	Ashley	**TOTAL**
- Styrofoam holder with frames and stands that have notches to hold the equipment.							
- styrofoam holder with rectangular compartments and claws to hold the funnels in place							
-rubber boot with triangular compartment stands							
Ethafoam material used in the design with containers placed on adjustable compartments/racks	1	1	1	1		1	5
-pouches that are waterproof and anti-bacterial has layered compartments that are open from the top							

Foam sleeves with removable elastic bands running throughout the drawer							
Rectangular components with a removable plastic wrap on top							
Funnels stored in pencil-case-like pouches that can be labeled and zipped up , stored in foam indents							
Base of foam / carpet with holes similar to bottom half of funnel where they can be stored	1	1		1	1		4
Large pole with extendable / closeable claws to keep funnels in place		1	1				2
Foam base with silicone molds to hold funnels in, with humidity controlling device		1	1		1	1	4
Suction devices that can be turned on / off to keep funnels in place with a cushioned base							
Metallic barriers that you can just take things out of with labels to communicate type of equipment / size							
Sideways dishwasher stands with cushioning and labels	1	1	1	1	1	1	6
A small, thin piece of fabric with with inflatable valve on end and stands to hold ends of funnels							
Laminated paper barriers with labels and foam / styrofoam base with indents							
Labeled foam pouches that can be opened / closed to store funnels in (no other additions)							

Double-sided claw that can be attached to the funnel stem (or equipment base) and to a storage rack							
Ethafoam material supporting the funnels divided into triangular compartments with shell or cave like shape of the design (open from the sides)							
shock absorbing materials (types of polymers) with frames to hold equipment in a vertical position							
Ethafoam material supporting the funnel; the design uses the shape of the flower bud may be used as a case for storing fragile equipment. The design can open and close automatically when users attempt to open it (by sensors)					1		1
Velcro-like material attached on the equipment's side and the interior of the design	1						1
Design contains vertically divided up sections and humidity levels are controlled; design detaches itself through detection/sensors		1	1	1	1	1	5
adjustable compartments or racks combined with net-like protection (spider web design)							
Claws that open and close(allow equipment to be stored/removed) and made of ethafoam material							
pouches that are waterproof and anti-bacterial combined with rectangular compartments	1	1		1		1	4
Stands that lock the equipment in place are placed in each of the small rectangular compartments							
rubber material for protection around the funnels with semi-circular	1		1	1	1	1	5

compartments with each equipment encapsulated within							
Shell shape of the design with styrofoam holders; this is similar to the storage of cups				1			1
Sensors for opening or closing the drawer (maintain force) and a digital monitor showing number of items and humidity combined with a rough surface at the bottom of the design to prevent movement of funnels; there are vertical dividers between the equipment							
Raised platforms (equipment stored in the middle of the platforms) and vertical dividers between sections made with ethafoam material			1	1		1	3
Metal frame with rods parallel to the width of the drawer. Rods are separated about the length of a funnel apart. indents/notches are in the rods to hold the funnels. Rods coated with rubber similar to stands that hold funnels during experimentation. Funnels can be stores in alternating directions	1	1	1	1	1	1	6
Similar to above, but use push and release locks to secure funnels in place							
Similar to above, but instead of a full frame, there are only sections (two rods, distance of separatory funnel apart with dents)							
Similar to first idea, with adjustable lengths for other drawers							
Line sides of the drawer with polyethylene foam / have compartments lines with polyethylene foam							

Many layers of polyethylene foam stacked together with holes for funnels carved out	1		1		1	1	4
IKEA summera drawer insert inspired → sections outlines by lifts in the mat, prevents rolling							
Triangular storage units size of the largest separatory funnel, lined with polyethylene foam							
Stands attached to bottom of drawer where separatory funnels can be placed (independent of size of drawer)							
Mat with stands where funnels can be stored (dependant on size of drawer)							
Individual plastic compartments the same size of large funnel (14 x 4 inch)							
Polyester stuffing. Thats it. And then u put the funnels in the drawer				1			1
Styrofoam stands which compartmentalize the different separatory funnels to its own size		1					1
Styrofoam base, shock absorbing material lining against walls, wood/metallic bases to prevent bumping into one another	1			1	1	1	4
Large compartment with smaller compartments inside which has a shell around each smaller compartment, every funnel is completely separate from one another due to the shells, with a styrofoam base layer		1		1	1	1	4
Ethafoam shaped specifically to the design which is used as a pouch, then placed on stands							
Circulator rubber pouches which roll around but still protect the separatory funnels during collisions, with shock absorbing materials on the walls and a ethafoam base layer			1				1

Pouches which drop down from the stands to fit in the funnels	1						1
Claws attached to the walls of drawer which secure all funnels in place	1						1
Secured clamps for each funnel which is lined with ethafoam on its clamp ends to minimize movement		1	1			1	3
Styrofoam mold with compartments and a lid to cover them	1	1			1		3
Rubber slot angled down with a drain to let any excess water, chemicals drain into a receptacle							
Use tubes wrapped in rubber boots to build stairs that overlap left, right, up and down							
Wrap the drawer with styrofoam and divide the drawer into triangular-shaped tiers with styrofoam compartment							
The entire drawer is covered with rubber, and there are small grooves customized according to different sizes on the surface to fix equipment			1	1	1	1	4

D3. Graphic decision chart

We began with 19 ideas and each ranked the idea on a scale from one to four depending on how well it satisfied our two main objectives. We then took an average of these scores to boil the results down to the final top five ideas which are highlighted with yellow, and two orange ideas from multi-voting.

Table 13. Individual Decision Ranking Score

1	Ranking Top 16 Ideas (2 or more votes)	AVERAGE ->	Safe (reduction in crack formation)	Cost effective ($$$)	Rank 1 (least)-4	Augustin	Augustin	Siaa	Siaa	Prantika	Prantika	Ashley	Ashley	Sam	Sam	Tyler	Tyler
2	Large pole with extendable / closeable claws to keep funnels in place		2	2.333333333		2	3	2	2	2	2	2	3	2	2	2	2
3	Raised platforms (equipment stored in the middle of the platforms) and vertical dividers between sections made with ethafoam material		2.833333333	2.166666667		4	1	3	2	1	3	4	2	2	3	3	2
4	Secured clamps for each funnel which is lined with ethafoam on its clamp ends to minimize movement		2.833333333	2.5		3	3	3	3	2	2	3	2	3	3	3	2
5	Styrofoam mold with compartments and a lid to cover them		3.333333333	3.166666667		3	4	2	3	4	3	3	3	4	2	4	4
6	Base of foam / carpet with holes similar to bottom half of funnel where they can be stored		3.166666667	2.5		4	3	3	3	3	2	3	2	3	2	3	3
7	Foam base with silicone molds to hold funnels in, with humidity controlling device		2.666666667	1.5		3	1	3	2	3	1	2	1	3	1	2	3
8	pouches that are waterproof and anti-bacterial combined with rectangular compartments		2.166666667	1.666666667		2	2	2	3	3	1	2	1	2	1	2	2
9	Many layers of polyethylene foam stacked together with holes for funnels carved out		3.666666667	3.333333333		3	4	3	3	4	3	4	4	4	3	4	3
10	Styrofoam base, shock absorbing material lining against walls, wood/metallic bases to prevent bumping into one another		3.666666667	2		4	1	4	1	3	2	4	2	4	4	3	2
11	Large compartment with smaller compartments inside which has a shell around each smaller compartment, every funnel is completely separate from one another due to the shells, with a styrofoam base layer		3.666666667	3.333333333		4	3	4	3	4	3	4	4	2	4	4	3
12	The entire drawer is covered with rubber, and there are small grooves customized according to different sizes on the surface to fix equipment		2.666666667	2.833333333		3	2	2	3	2	3	3	3	3	3	3	3
13	Ethafoam material used in the design with containers placed on adjustable compartments/racks		3	3.166666667		4	4	4	2	3	3	3	4	2	4	2	2
14	Design contains vertically divided up sections and humidity levels are controlled; design detaches itself through detection/sensors		3	1.166666667		3	1	4	1	3	2	3	1	2	1	3	1
15	rubber material for protection around the funnels with semi-circular compartments with each equipment encapsulated within		3	2.333333333		2	3	3	2	3	2	4	2	3	2	3	3
16	Sideways dishwasher stands with cushioning and labels		2.5	3		3	4	3	3	2	3	3	3	2	3	2	2
17	Metal frame with rods parallel to width of drawer. Rods are separated about the length of a funnel apart. indents/notches are in the rods to hold the funnels. Rods coated with rubber similar to stands that hold funnels during experimentation. Funnels can be stores in alternating directions		2.333333333	1.166666667		3	1	3	1	3	1	2	1	1	1	2	2

Three of these ideas (Ideas 5, 9, 11) were similar, but each had some slight variation, so they were combined to arrive at the top 5.

D4. Weighted decision matrix

A weighted decision chart used to rank the remaining five ideas. First evaluate the importance of each objective to the project, so that the total sum equals 100%. Then each idea is evaluated for the degree of satisfaction of each objective, with a maximum of 100%. Finally, the two tables are merged, and the top three enter the next step of evaluation.

Table 14. Weighted decision matrix

	RANK OF OBJECTIVES	VALUE OF OBJECTIVE
Reduce crack formation	1	30%

Cost effective	2	25%
Easy to manufacture	3	15%
Ease of use / time efficiency	4	12%
Withstand weight	5	10%
Space efficiency	6	8%
TOTAL		100%

Table 15. evaluate the importance of each objective to the project

How much each idea meets the objective	Foam container with separate sections to store each separatory funnel. Holes in the shape of the equipment being stored.	Metal frame with rods parallel to the width of the drawer. Rods are separated about the length of a funnel apart. indents/notches are in the rods to hold the funnels. Rods coated with rubber similar to stands that hold funnels during experimentation. Funnels can be stores in alternating directions	Sideways dishwasher stands with cushioning and labels	Styrofoam base, shock absorbing material lining against walls, wood/metallic bases to prevent bumping into one another	Large compartment with smaller compartments inside which has a shell around each smaller compartment, every funnel is completely separate from one another due to the shells, with a styrofoam base layer
Reduce crack formation	80.00%	70.00%	70.00%	70.00%	40.00%
Cost effective	65%	90%	80%	75%	60.00%
Easy to manufacture	85%	40%	60%	70%	60%
Ease of use / time efficiency	100.00%	100.00%	80.00%	100.00%	80.00%
Withstand	87%	100.00%	100.00%	90.00%	80.00%

weight					
Space efficiency	65.00%	70.00%	85.00%	60.00%	10.00%

Table 16. combine 2 table together

COMBINE TWO TABLES					
Reduce crack formation	24%	21%	21%	21%	12%
Cost effective	16%	23%	20%	19%	15%
Easy to manufacture	13%	6%	9%	11%	9%
Ease of use / time efficiency	12%	12%	10%	12%	10%
Withstand weight	9%	10%	10%	9%	8%
Space efficiency	5%	6%	7%	5%	1%
TOTAL	79%	77%	76%	76%	54%

D5. Pugh Method

The Pugh method is used to score the top three according to the degree of satisfaction of each objective, -3 is the lowest and 3 is the highest. Finally, a top three ranking list is obtained.

Table 17. Table showing the Pugh method

Objectives	Datum	Alternative 1	Alternative 2	Alternative 3
	Datum (funnels stored randomly with some bubble wrap and cloth)	Foam container with separate sections to store each separatory funnel. Holes in the shape of the equipment being stored.	Metal frame with rods parallel to the width of the drawer. Rods are separated about the length of a funnel apart. indents/notches are in the rods to hold the funnels. Rods coated with rubber similar to stands that hold funnels during experimentation. Funnels can be stores in alternating directions	Styrofoam base, shock absorbing material lining against walls, wood/metallic bases to prevent bumping into one another
Reduce crack formation	0	2	3	1
Cost effective	0	1	3	2
Ease of assembly	0	-1	-3	-2
Ease of use / time efficiency	0	1	-1	1
Withstand weight	0	1	1	2
Space efficiency	0	1	1	1
Sum	**0**	**6**	**4**	**5**

Appendix E: Objective Comparisons

E1. Foam container with holes for equipment

Since a higher coefficient of friction should correspond to a lower glass maintenance cost due to less movement of funnels, the glass maintenance costs should be moderately reduced compared to the other designs, as it has a coefficient of friction between 0.34 and 0.6.

Cost of building is ~$350, for the cost of foam [25].

Time to build design taken from [26]. It took just under 2.5 hours to cut foam for 6 drawers, so using that as a baseline, it should take ~25 minutes for a drawer.

The estimate of time to use the drawer was based on experimental research. A drawer was opened, an item taken out of it, and the drawer was closed again. In total, the process took about four seconds.

Mass held was determined by dividing tensile strength of material by area and gravitational constant.
Tensile strength for polymer foams is about 3.99 MPa [24];
3 990 000 Pa / [(0.552 m^3) / 9.81 m/s^2] = ~736 kg.
Note that this does not take into account the possible structural failure of the drawer itself, which is out of scope.

E2. PVC Pipes and 3-D Printed Rods

Since a higher coefficient of friction should correspond to a lower glass maintenance cost due to less movement of funnels, the glass maintenance costs should be highly reduced compared to the other designs, as it has the highest coefficient of friction (0.6).

Cost to build is about ~$80, $65 for the PVC piping, $6 for 3D printing, and $10 for the rubber coating [29][30].

Time taken to build design takes a baseline of Idea 1 and [26], but with consideration for the extra time to attach and secure more individual pieces. Through estimation, time to assemble is about 1.5 hours (0.5 hours for PVC pipe setup and 0.25 hours to attach each 3-D printed rod).

Time to use the design is similar to the first idea (~4 s). However, extra care will need to be taken as there is no protective cushioning other than the rubber. To account for this, the time was multiplied by a safety factor of 1.25, bringing the usage time to 5 s.

Mass held was determined similar to the first idea.
27.6 MPa / [(0.552 m^3) * 9.81 m/s^2] = ~5 100 kg [28]. The tensile strength of super glue was taken in this case, as this would be the first component to fail (as opposed to the 3-D printed rods).

E3. Styrofoam Base with Compartments

Since a higher coefficient of friction should correspond to a lower glass maintenance cost due to less movement of funnels, the glass maintenance costs should not be as reduced compared to the other designs, as it has the lowest coefficient of friction (0.34).

Estimating cost of glassware repair same as first idea (same material for base and cushioning).

Cost to build is about $128, $60 for the styrofoam base and $68 for the compartment materials [31][32].

Time to build is similar to the first idea, but with additional time to set up compartments, so the original 30 minutes were multiplied by a safety factor of 2.

Time to use the design is similar to the first design (~4 s).

Mass held: Tensile strength of styrofoam is 450 kPa [24].
31.8 MPa/(0.552 m^2/9.81 m/s^2) = 5872 kg.

E4. Number of Funnels That Can Be Held

This is used universally, as all alternative designs require the funnels to be organized in the most space-efficient manner possible.

Large funnels: 14 inch by 4 inch
Medium funnels: 12.5 inch by 3.5 inch
Small funnels: 11.5 inch by 3 inch

Length of Drawer: 45.5 inches

Lengths of funnels, total: 14 + 12.5 + 11.5 = 38 inches.
About 1 inch of space is left between the funnels and the sides of the drawers.

Width of drawer: 19 inches

Large funnels: 19/4 = 4.75. However, because we want to leave enough space between the funnels (about 1 inch), 3 large funnels can be stored. (3 x 4 = 12 + 4 = 16 inches)

Medium funnels: 19/3.5 = 5.4 funnels. Again, we want to leave enough space in between funnels, so the design stores 4 medium funnels. (3.5 x 4 = 14 + 5 inches for space = 19 inches)

Small funnels: 19/3 = 6.3 funnels. Leave 1 inch of space in between. Stores 4 small funnels. (3 x 4 = 12 + 5 inches for space = 17 inches total)

Total: maximum 11 funnels for each design

Appendix F: Attribution Table

Tutorial #:	TUT0104	Team #:	017
Assignment:	Conceptual Design Specifications	Date:	March 26, 2023

The Attribution Table is a major resource used by your TA in determining whether there was equal contribution to the team assignment. If your TA determines that there was significant under contribution, then they may apply an individual penalty to the under contributing team members' grade. As a future professional engineer you should NOT sign any document you have not read and do not agree with.

The Attribution Table must be completed, signed by all team members, and submitted to your TA for each team assignment. Check the course schedule for the deadline for submission. Check with your TA for the method of submission. Teams who do not submit a completed form, including those that submit an incomplete form, such as one missing a team member's signature, will receive zero on the assignment. The team may submit a petition to the ESP Office if they feel the lack of signature is through no fault of the team.

The Attribution Table should accurately reflect each team members' contribution to the document. Be sure to keep a copy of this form for the team's records.

If there are irreconcilable differences that are preventing all team members from signing the attribution table then each team member must write a letter (<one page) explaining their position on the difference and suggest a solution. These letters much be submitted to the TA.

As with any engineering statement this attribution table must be backed by credible evidence. In most cases this will be found either in the Google Docs document revision history, or your engineering notebook. Making fraudulent claims in an Attribution Table displays intent to deceive and is a serious academic offence.

Please note: the "Idea Generation" Document, microsoft teams meeting, project requirements document, and the google sheets idea selection/generation document contains more detailed information in the version history of the contributions to the project prior to and during the team meetings.

Section	Student Names					
	Augustin Chuachiaco	Siaa Gor	Sameen Islam	Tyler Gosal	Prantika Saha	Ashley Wang
Entire Document				FP		
Executive Summary			ET		WD	
Introduction			ET	ET	WD	

Problem Statement	ET	ET		WD, MR	ET	
Service Environment	WD	ET		FP	ET	
Stakeholders		ET	WD, MR	FP	ET	ET
Functions		WD, ET		ET	ET	
Objectives	ET	WD, ET RS1,RS2, MR	ET	ET	ET MR	ET
Constraints	MR	ET		ET	ET	WD, MR, ET, RS5
Idea Generation		WD,MR	ET		ET	
Brainstorming	OR2, WD	ET		ET		ET
Morph Chart	OR2	WD		ET		ET
SCAMPER, biomimicry, magic solutions	OR2	WD		ET		ET
Idea Selection	ET	ET			ET	WD, ET
Alternative Design Descriptions	WD, ET	MR, OR1	ET	ET	ET, OR1	ET
Proposed Conceptual Design	ET	ET	ET	WD, MR		
Measure of Success	ET		WD		ET	ET
Conclusion		WD,ET	ET		ET	
References				WD, MR		

Appendix A		WD,RS3, RS4				
Appendix B		WD,RS3, RS4				
Appendix C	ET	WD/ET				
Appendix D		ET				WD, MR
Appendix E	WD, RS8					

Fill in abbreviations for roles for each of the required content elements using the abbreviations found on the next page. You do not have to fill in every cell.

RS – Research (give details below) WD – Wrote Draft MR – Major Revision ET – Edited	FP – Final Proofread of COMPLETE DOCUMENT verifying for flow and consistency OR – Other (give details below)

If you put RS (research) please add a number identifier such as RS1, RS2, etc. Give the research question / topic:

RS1:
How much kinetic energy and work is needed to operate the design?

RS2:
How much does a typical separatory funnel made of Borosilicate Glass 125ml weigh?

RS3:
What is the main material used to create the drawer? This will be used to benchmark it to the cost of the project.

RS4:
How much does the material of the drawer cost?

RS5: Lab safety standards

RS6: Properties of borosilicate glass, a material often found in lab equipment.

RS7: Stakeholder interests

RS8: Objective comparisons

If you put OR (other) please add a number identifier such as OR1, OR2, etc. Explain the role below:

OR1: Drew Sketches for Alternative Designs

OR2: Led process

By typing your name below to sign, you verify that you have:

- Read the attribution table and agree that it accurately reflects your contribution to the associated document.
- Written the sections of the document attributed to you and that they are entirely original.
- Accurately cited and referenced any ideas or expressions of ideas taken from other sources according to the standard specified by this course.
- Read the University of Toronto Code of Behaviour on Academic Matters and understand the definition of academic offense includes (but is not limited to) all forms of plagiarism. Additionally, you understand that if you provide another student with any part of your own or your team's work, for whatever reason, and the student having received the work uses it for the purposes of committing an academic offence, then you are considered an equal party in the offence and will be subject to academic sanctions.

Student #1 Name	Sameen Islam	Student #4 Name	Tyler Gosal
Student #2 Name	Siaa Gor	Student #5 Name	Ashley Wang
Student #3 Name	Prantika Saha	Student #6 Name	Augustin Chuachiaco