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Integrating engineering drawing into sketching to assist and improve severe sketching skills deficits and to support the creative process

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ABSTRACT

This study investigates a prevailing problem observed among a very high number of undergraduate design students during the foundation year – mainly the severe lack of essential sketching skills compared to technical drawing and low creativity during the sketching phase. The differences and connections between sketching, technical drawing, and creativity were examined in the study. In addition, the working of the human mind as related to sketching and the creative process, and factors that negatively affect the novice design student, directly and indirectly influencing student performance, was investigated. The study aims to establish a practical solution that can assist and help students alleviate challenges in the realm of sketching and creativity. As a result, a tool is proposed, that integrates this experience, investigation, and observation into a simple, straightforward, usable, easy-to-apply, practical solution that can fit and blend in with the current curriculum and time constraints of the design foundation year and be of benefit students in the design or engineering fields who struggle with basic sketching skills and the creative process during the sketching phase of projects.

KEYWORDS: design & engineering, technical drawing, sketching, process, tool

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1. Introduction

1.1 Difference between Engineering Drawing, Freehand Sketching, and the role of Technology.

Engineering drawing and sketching are important part of the higher education curriculum in all design and many engineering disciplines. There are important differences between Engineering (technical) drawing and sketching. An engineering drawing is a *"detailed description of an engineering system of a design, with exact dimensions"* (Martin-Erro et. al.2016). Engineering drawings are vital for communicating ideas in engineering and industry. To make the drawings easier to understand, people make use of familiar symbols, units of measurement, perspectives, notation systems, page layout, or visual styles. Together, such conventions make up a visual language that helps ensure that the drawing is not ambiguous and relatively easy to understand (Technical Drawing, Teachmint, 2023).

A sketch on the other hand has been defined as *"a preliminary rough representation without detail, usually rapidly executed to present only key elements of the design"* (Pei E et al. 2011). It is *"a tool for thought rather than just a recording medium"* (Hope 2008). *"In the early stages, sketches are fast, ambiguous, mostly only meaningful to the designer. Their abstractness allows the imagination to work. They leave room to try out possibilities without committing prematurely"* (Ceren A.Y. &Kandemir O, 2021). Buxton & Buxton (2010),describe design sketches as quick, timely, cheap, disposable, multiple, with clear visual vocabulary, with specific features that distinguish them from other visual representations, with a sense of freedom, minimal detail, and ambiguity because they are open to interpretation. Eckert (2004) describes sketching as *"an informal drawing on paper with rough details"*. Tversky (2002), states that sketches are a form of communication like the spoken or written language. Freehand sketching has been shown to be important because it connects students' hand movements and their mental thinking ability. Sketching has been shown to be helpful in providing quality design solutions (Schutze M., 2003) and Ferguson (1994), identifies several types of sketches among which is thinking sketches (to support individual thinking processes), talking sketches (to communicate with others), and prescriptive sketches (to represent the sketched idea).

Over the last decades, expectations about design education have changed following the paradigm shift of our times, with a strong and increasingly use of the new technologies. However, *"most designers still base their work on sketches"* Silva, A.M., 2022). *"Sketching by hand, with a pen or pencil on a piece of paper, is still one of the best ways to design. It is tough to beat physical drawing for speed, for expressiveness, and for convenience"* (Bacus J., 2020). *"Hand drawing is no less important today than it has been in the past. The computer cannot become a complete replacement for the way in which designers conceptualize and communicate their designs"* (Grisinger G., 2013). *"In the current era of automated technocratic designer work, sketching still remains irreplaceable"* (Spacek R, et al, 2016). In addition as (Henry K, 2012) put it beautifully in his book, when asked by students why they need to sketch in an age of computing, his answer was *"Garbage in = Garbage out"* meaning they will get out of the computer only what they are able to put into it. The computer may improve some visual aspects of the sketch or drawing, but it cannot for example hide a weak concept with badly chosen proportions under beautiful renderings and other visual effects. Freehand sketching has been confirmed to play a vital role in design and engineering education, so attempts to strive to keep improving this skill is highly important for the success of any designer. Tipping C.(2009), argued that sketching ability may be *"the single most important factor in developing any general design ability"*. In the case investigated in this study the use of technology has been left out due to additional reasons, mainly limited availability and high cost involved. In Table1, a summary is provided of what manual freehand sketching and manual technical drawing is by comparing their differences. It is clear that Fidelity level is the major aspect differentiating the sketch from the technical drawing. The term *"Fidelity"* dates back to the 1930's. The term today is used in the design world to *"differentiate refined and realistic from quick and schematic"* (Henry K, 2012).

Table 1.The Freehand Sketch versus the Technical Drawing: A Comparison

The SKETCH Drawing **(Manual)** **How, When, What, & General Characteristics**	**The Technical/Engineering DRAWING** **(Manual)** **How, When, What, & General Characteristics**
• **Is mostly Subjective, Emotional**	• **Is Objective, Non-emotional**
HOW?	**HOW?**
Drawing Freehand using most commonly Pencil/ Pen/Paper	Drawing using manual drafting tools and instruments and paper, Drafting Pencil/Pen
WHEN?	**WHEN?**
Done prior to the technical drawing stage and involves a number of different concepts/sketches of different ideas	Done after the sketching phase and involves redrawing the selected concept/ sketch/ drawing using drafting tools turning a concept into a final drawing
WHAT (used for)?	**WHAT (used for)?**
Tool for thinking, ideas are in progress, unfinished.	Tool for showing a finished idea, not much room for change. Thinking process completed
Tool for Communication, Serves as international language and should be understood by all (no special knowledge required)	Tool for Communication, Serves as international language. Some technical knowledge is required depending on the type of drawing. May not be readily understood by all viewers.
General Characteristics	**General Characteristics**
Ambiguous - Encourages Interpretation and can have several meanings	Unambiguous - Doesn't encourage interpretation. It should be only read and can have only one intended meaning
Plentiful, presented with many options. Open for development	Presented as one finished idea fully developed. Difficult to make changes
Creative, Exploratory, Dynamic	Refined, Perfected, based on an established idea, not much room for creative development.
Rough appearance, More free , less rigid	Clean appearance, Rigid, Involves following a lot of rules
Fast, Speedy, Not time consuming	Slow, Carefully done, Time Consuming
Schematic, Less detailed, general, partial	Realistic, Accurate, Detailed, Complete
Mainly explores form by visually judging proportions, scale.	All measurements have been worked out and finalized

Legibility level can be just enough to make the idea clear to all viewers	Highly legible, but may require technical knowledge to understand
Less expensive	More expensive

1.2 The Brain, Creativity and its connection to Sketching and Drawing

Creative thinking has been described as *"a way of moving beyond barriers"* (Mumaw S., 2012). Bateson and Martin's (2013) definition is *"generating novel actions or ideas, particularly by recombining existing actions, ideas or thoughts in new ways or applying them in new situations"*. The human brain's evolution caused the prefrontal cortex to develop, which, according to (Eagleman D., 2019) *"gave us our imagination, setting us apart from other animals and making us uniquely creative"*. Successful Creativity involves generating both useful and original ideas, or we can say creativity involves the interaction of "divergent and convergent thinking" (Guilford J. P., 1967). Mednick,(1962), described creativity as *"the forming of associative elements into new combinations which either meet specified requirements or are in some way useful"*. Sketching has traditionally been considered as a means to *"spur creative thinking"* (Hua M. 2019). The great thing about sketching is the freedom it affords. Because it is such a fluid medium, it allows us to reach deep into the well of creativity and explore possibilities without feeling constrained to any particular outcome (Schütze et al., 2003). *"Design teams produce higher-quality solutions to a design problem when they are permitted to sketch"* (Camba et al. 2018). Belardi et al. (2019), expresses that sketches are able to combine the artists *"creative act and the scientists invention"* and eliminate the division in between. Sketching is understood as *"a key factor for creative expression, one the most effective visual thinking tools"* (Martin-Erroet al.2016). Scientists have proven the benefit of sketching for creativity, calling it *"restructuring"* that drive on creative transformations (Verstijnen et al. 1998;Silva, A.M, 2022).

Engineering Design researchers as well as professionals agree on the value of sketching to enhance visual thinking and so creativity. Written and spoken language is often not enough to express creative ideas. Visual expression through sketching can explain much more in a more straightforward, easier-to-understand manner for all viewers, regardless of language background. As (Hsu and Woon, 1998) put it visual thinking models are *"the closest way to humans of thinking and reasoning"*. Two networks have been identified in the brain that has to work together for creativity to result: The Default Mode Network (DMN network) is activated in divergent thinking and generating of new ideas. Here we have a more free flowing, less restricted, less planned, less organized, highly spontaneous thinking and feeling process happening, where all kinds of associations and combinations may be explored leaving possibilities wide open without restrictions and inhibitions. The Executive Control Network (EN Network) on the other hand is activated when there are rules to follow, in evaluating and selecting ideas, in planning, in focused thinking, evaluation, solving problems, inhibitions (De Pisapia et al. 2016). These two networks are considered to be in *"opposition"* and *"competition"* with each other, yet for creativity to result there must be interaction and *"coordination of activity between different brain regions in order to achieve a task"* (Friston, K. J, 2011).

Edwards (2009), in her book identified that *"we have a double brain with two ways of knowing"* in our heads and depending on the nature of the task given one of the hemispheres may take over while inhibiting the other. This depends on which hemisphere can do the job quickest, likes and enjoys the task or hates the task at hand. Edwards developed exercises that can help make the (L) to (R) Hemisphere *"switch"* and thus improve student's ability in drawing objects they try to replicate on paper by observation. These exercises are focused on *"blocking-out distractions"* and focusing only on the lines, shapes, colors, and values. (Edwards B, 2009). This works well when it comes to representational drawing skill, however it does not directly work on enhancing creativity through drawing (a skill much needed in design and engineering). Students, who are excellent in drawing by observation, may still severely lack creativity, as the ability to copy a drawing does not equal to being creative. Both skills are beneficial however and have purpose and use as (Ostrofsky J, 2015), said *"Specific transformations that result in errors of perceptual judgment can result in similar drawing errors"*, so learning to see and perceive correctly is also important to master. However in the design field here at YU specifically, there is one major problem observed especially among novice students. Even those students, who embark on the design undergraduate program with better drawing skills, because they had some previous experience or have completed fine-art courses, still may lack severely in creativity, because they remain within the mind-set that

design means to copy what we see around us in a beautiful and realistic manner. Therefore sketching exercises and methods should be geared aggressively towards developing the skill of sketching in a way to serve the creative process, rather than as a goal in itself to correctly observe and replicate objects, but the skill itself needs also to be developed, to offer students a means to express their creative ideas visually, rather than trying to use spoken language.

1.3 Basic components of Sketching and Drawing: Lines &Angles

What are Lines and Angles

Lines and angles are the basic concepts of geometry. They are also the most basic structural elements that form a sketch and technical drawing. A line has only one dimension (length). An angle is defined as a figure created by two lines that meet at a common endpoint and are measured in degrees. All geometrical shapes are composed of lines and angles and all objects are comprised of basic geometrical shapes, no matter how complex they appear in their final form.

The purpose of Lines and Angles in Sketching and Engineering Drawing

The purpose of using lines and angles in sketches is to communicate shape and form clearly. *"Lines are placed for different reasons, e.g., to indicate the boundaries of objects"* (Sheng Het al. 2021). Lines can be used for simple organization or for conveying complex meaning. In sketching, most lines and angles can be estimated, while in engineering (technical) drawing dimensions must be used precisely. In engineering drawings a variety of very specific lines exist to communicate specific detailed objective information. These lines have clearly defined thicknesses and many other details differentiating one line type from the other. Changing even the slightest detail may result is miscommunication of the intended message. On the contrast in Freehand Sketching the use of lines is also numerous, but here a line viewed on its own does not communicate anything specific, but rather all the lines of the sketch together are judged in unity and sometimes together with context and determined what they communicate together as a group not individually. Together as a group they can greatly influence the way a sketch is understood and perceived by the viewer and may even express emotional aspects influencing the viewer in ways that technical drawings cannot.

Therefore both technical drawing and sketching use a large variety of lines as a language for communication, but the types and purpose of use can vary greatly. During creative idea generation through sketching, lines and angles can be used to explore different visual possibilities and experiment with different design concepts; this multitude of creative visual results are made possible by using random lines, which has been identified as an effective technique for generating new concepts. *"Random lines can inspire unique shapes and forms from which innovative designs can emerge"*(Mukhopadhyay, S, 2013). In addition varying the scale and proportion of the lines and angles and resulting objects and sub-objects during sketching can also result in many creative variations. Both size and proportion are judged and organized subjectively in sketching.

How the Brain interprets Lines and Angles in Sketches

The (R) Brain is *"the part of the brain that can nonverbally assess relationship of sizes, curves, angles, and shapes"* (Singer Johannes J.D et al. 2023). *"Line drawings captured only coarsely how objects look in reality, were still perceived as resembling real-world objects by the viewers"(*Singer Johannes J.D et al. 2023). This is important as it shows that too much detail is not needed in preliminary sketching where the priority is in numerous idea generation rather than clear object recognition and quality appreciation. The idea that too much detail is not needed in preliminary sketching(using lines and angles), has also been shown by (Biederman I. &Ju G. 1998;Eitz M. et al. 2012). *"We can identify objects in simple and abstract line drawings with similar speed and accuracy as natural object images"* and also by (Cavanagh P. &Sayim B,2011) when they identified that when a set of contours (i.e. outlines) matches a familiar prototype, the memory serves to fill in the missing details.

Challenges of using Lines and Angles in sketching

There are challenges when using lines and anglesin sketching for concept generation. One common challenge is achieving accuracy is when drawing lines freehand. Other challenge designers may face when using lines and

angles during sketching is *"maintaining perspective accuracy"* (Shikhmurzaev Y. D, 2020). Also 3D sketching has been found to be more difficult than 2D sketching. Sheppard E. et al. (2005), conducted an experiment that compared drawing accuracy between depictions of familiar and unfamiliar model objects that were presented with and without 3D cues. Overall, drawings of models with 3D cues were found to be less accurate than drawings of models without 3D cues (Ostrofsky J.et al. 2017). This means that for most students *"it is easier to start with 2D drawings to get a sense of proportion, and get their imagination working"*, and only later on to move on to 3D drawing (Waanders R. et al. 2011).

2. Research Design and Methods

This study focuses on three major issues

1. To better understand the lack of essential sketching skills and low creativity among students during their foundation year of study.
2. To identify factors that can be directly and practically addressed through a designed intervention, which can be easily and inexpensively implemented into the current curriculum among its current constraints.
3. To design the possible intervention/s and start preliminary testing

To achieve the research objective a **Qualitative Analysis** approach was used:

- Descriptive data was collected through observation of student behavior and performance on specific exercises, projects, and assignment tasks and recorded. The focus was on tasks that require predominantly sketching and technical drawing skills, as well as creativity, as this is the focus of the study.
- Unstructured one-on-one interviews and focus groups were used to gather descriptive data about behavior and to identify reasons and patterns governing issues students have that may influence directly and indirectly their current skill level and abilities. The informal setting and flexibility of the unstructured interviews was the most suitable method considering the circumstances which included a lot of unknowns that needed to be identified. Also most undergraduate students who enroll at the design program, come from backgrounds that causes them to exhibit reserve in unfamiliar surroundings and in new environments or when talking to higher authority (such as a teacher). This sometimes results in limited or partial response if asked a direct question that sounds important and formal. Also students language skills in English are below optimal, so many misunderstand written information or formal questions if not explained to them in simple and alternative ways. In addition many students have trust issues, so are not willing to easily disclose personal information or issues they consider personal.
- Time period of study: 6 semesters spanning over three years from 2021 – 2023.
- Number of students interviewed: 210 randomly selected students were questioned and their answers analysed and considered for this study.
- Total number of Students observed throughout the study: 494

The study used three courses which students take among others during the foundation year taught from 2021 – 2023. Those are

- DES 101 Introduction to 3D Drawing
- DES 212 Engineering Drawing & Model-making
- DES213 Ergonomics(Human Factors Engineering)

These courses were chosen for several reasons:

1. Experience in teaching these courses multiple times by the author.
2. These courses contain all required skills that this study investigates, however each course has a different degree of each skill in its content. For example one course may involve more technical drawing, while another more sketching, or creativity. All other skills or content that these courses cover but are not part of the focus of this study is placed under "Other Content" (this includes theoretical knowledge tested through exams, analytical skills, methods, techniques, and physical model making using a variety of materials, basic research, class participation, and more. See Table 2 for a general percentage breakdown of content.
3. Currently no courses are available in the curriculum dealing exclusively with teaching students sketching

or any freehand drawing. For this reason other courses had to be chosen for this study that fit the criteria - to be a foundation year course and to have content related to sketching, technical drawing, and creativity.

Considering all the three courses together technical drawing comprises currently the majority of the content in the tasks of the courses, followed by other Content, Sketching, and finally Creativity (Table2).

Table 2 Breakdown of Sketching, Technical Drawing, Creativity, and Other content in tasks for the three courses

Course	Sketching%	T. Drawing %	Creativity%	Other Content%
DES101	50	50	0	0
DES212	20	40	20	20
DES213	5	15	10	70
Total % based on content	**25%**	**35%**	**10%**	**30%**

The purpose of sketching practiced in the current foundation courses is for two main purposes:

To learn the skill of sketching through basic exercises. Understanding how sketching can be used on a very basic level to communicate creative ideas and to visually express solutions to problems by completing basic projects and assignments.

The purpose of technical drawing practiced in the current foundation courses is mainly for:

To learn how to use the drafting tools and all the standard rules that come with technical drawing.
Its importance and use for the pre-construction phase of physical models and simple working prototypes after the sketching phase has been completed and the best concept selected.

Table 3 compares student scores for the three courses which included several sections of each course that were added up for to simplify comparisons. Using the official university records the number of students that lie within each grading category was identified. Also using the records the average was taken for each course and then calculated for all courses together, to give an idea of the general level of achievement. It is clear from this table and the average; the grades lie on the Pass – Fair spectrum, which is very low.

Table 3 Comparison of student grades for three class types taught over a period of six semesters (three years)

Year	Course	Total (n) of Students (from all sections)	Student (n) Grades 0 – 59 Fail – Pass %	Student (n) Grades 60 – 79 Fair - Good %	Student (n) Grades 80 – 100 V. Good– Excellent %	Mean Value %
2021-23	DES101	207	85	71	51	64.72
2021-23	DES212	127	43	69	15	65
2021-23	DES213	160	88	59	13	58.8
Total		**494**	**216**	**199**	**79**	**63.2**

In Table 4, the focus is on Sketching and Technical Drawing to make a comparison between the two skills. Table 4 shows students divided into several types, based on skill combination. An arbitrary score from 0-3 was used to show skill level ranging from low to excellent. Low = 0 Average = 1 Good = 2 Excellent = 3.

The lettering A through G is used to simplify the reference to each skill combination based on score. Skill combination types that have not been encountered yet in the three chosen courses for this study during the six semesters are marked with NO. Such are C3, D1, D3, D4, E3, F2, G1.

To reach this conclusion notes were taken throughout the semester observing each student performance on different exercises and projects that required sketching and technical drawing and a final score from 0-3 was given for each student at the end of the semester for each skill. The percentage of students in each grade category based on skill combination type was then calculated to give a general indication of which skill combinations are

prevalent in each of the three grade categories. Table 4 summarizes the result.

Table 4 Categorization of students according to Sketching & Technical Drawing Skill combination type and scores based on task level

Type	Sketching Skills & Technical Drawing Skills Combinations	Score 0-3	Total Score	Skill Combination Encountered among Novice Students	Number of Students	% of Students from Category	Overall score range
A1	Low sketching skills Low drawing skills	0 0	0	YES	153	71	Fail - Pass 0 - 59
B1	Low sketching skills Average drawing skills	0 1	1	YES	57	26	
B2	Average sketching skills Low drawing skills	1 0	1	YES	6	3	
C1	Low sketching skills Good drawing skills	0 2	2	YES	115	58	
C2	Average sketching skills Average drawing skills	1 1	2	YES	32	16	
C3	Good sketching skills Low drawing skills	2 0	2	NO	0	0	Fair -Good 60 - 79
D1	Low sketching skills Excellent drawing skills	0 3	3	NO	0	0	
D2	Average sketching skills Good drawing skills	1 2	3	YES	52	26	
D3	Good sketching skills Average drawing skills	2 1	3	NO	0	0	
D4	Excellent sketching skills Low drawing skills	3 0	3	NO	0	0	

E1	**Average sketching skills** **Excellent drawing skills**	1 3	4	YES	63	80	**V. Good - Excellent** **80 - 100**
E2	**Good sketching skills** **Good drawing skills**	2 2	4	YES	11	14	
E3	**Excellent sketching skills** **Average drawing skills**	3 1	4	**NO**	0	0	
F1	**Good sketching skills** **Excellent drawing skills**	2 3	5	YES	5	6	
F2	**Excellent sketching skills** **Good drawing skills**	3 2	5	**NO**	0	0	
G1	**Excellent sketching skills** **Excellent drawing skills**	3 3	6	**NO**	0	0	

Low = 0 Average = 1 Good = 2 Excellent = 3

Factors influencing negatively the novice student that that were collected through interviews and focus groups as well as indirectly by observation and by examining the curriculum content, student acceptance rates and being part of the entrance exams evaluation team, are documented and categorized according Direct and Indirect factors as shown in *Table 5*.

Table 5Ashows factors that can be to some degree directly influenced inside the classroom through the introduction and use of certain methods and other interventions, while Table 5B shows wider societal factors that cannot be directly or easily modified or influenced and are beyond the scope of this study, however understanding them gives a more complete depiction of the multifaceted problem at hand and a more clear understanding of the psychological & cultural influences that may contribute to the issue investigated in this study.

Table 5 Factors affecting and influencing the novice design student
5A. Direct Factors identified which affect negatively the basic skills

A. **Direct Factors**	**Reasons Identified**
Fear when approaching sketching/ drawing tasks	• Because of a lack of drawing experience in general or lack of proper and useful experience

Fear of the teachers response	• Criticism is taken personally by many students and the reaction is negative and de-motivational on most occasions
Fear of the unfamiliar	• Students are not clear what all this "sketching, drawing and designing" is really all about, and its purpose, believing it is about personal choice and to decorate objects
Fear of getting shamed in front of others	• What friends think is very important for most students
Fear of the result	• Attempts to make the sketch/drawing the "correct" way, i.e., to be a "beautiful" drawing is a constant concern and reason to block creativity and experimentation attempts.
Fear of the blank page	• How and where to start is "confusing" without clear step-by-step guidance from the teacher.
Fear of Failure due to inability to draw	• Failure for most students means mainly getting "bad marks" in a particular class. Many students lack the realization that skills learned in one class will be needed later in other classes, so the broader concept of success or failure is not well understood.
Confused by the word "creativity"	• Not really understanding what creativity is. • Believing that creativity always goes hand in hand with drawing, so if you can't draw you can't be creative either. • Believing that creativity means producing "beautiful representational drawings" • Not trained how to enhance creativity. • Copy- Pasting or drawing only what is directly seen is considered safer than experimenting with new ideas • Unable to show creative ideas due to a severe lack of drawing skills, so most students prefer to explain ideas verbally.
Believe that Sketching ability is a Talent	• A general believe exists among students that you either "can or cannot draw" and that this can't be changed through practice. As a result many students use this as an excuse why they just can't do the tasks. In other words it's not in their hands.
Believe that Sketching and Drawing by hand is not important for a designer	• A general believe exists among students that learning how to work on computer applications is what ultimately makes a designer.

Entrance Exam for Design is way too easy & High-School grades needed for acceptance are very low.	• To be accepted to study design at YU is based on an entrance exam which is way too easy to pass, allowing many students to be accepted into the department with literally zero skills. The high school acceptance marks to study Design are among the lowest compared to other fields of study of which Medicine ranks the highest.
<u>Curriculum Design Problems:</u> a) Not enough importance placed on developing sketching skills b) Important courses are missing that should be present in the foundation year curriculum c) A lot of courses fill up the curriculum that are compulsory for students to take, but are irrelevant to design.	• No courses available to strengthen sketching skills directly. Students are expected to perfect these skills somehow indirectly through other courses and projects. This is mainly due to a rising level of content that needs to be covered within a limited time period, causing certain important skills such as sketching that needs time to be properly mastered, to be barely touched upon before jumping to other content, racing through classes without proper time to process and practice the information • It should be noted that at the beginning of their study undergraduates are immediately exposed to three dimensional drawing and design and technical drawing before having explored the two dimensional drawing space first, or going through a course focused on basic freehand sketching and drawing. • This can be beneficial for gaining general knowledge, but the number of courses are occupying too much of the student time, which could have been used for courses designed to strengthen skills directly needed for design. For this reason much remains untaught or under-taught, quickly skipped thorough, moving on to more advanced design courses without proper basic preparation.

Table 5 Factors affecting and influencing the novice design student
5B. Indirect Factors identified which affect negatively the basic skills

B. **Indirect Factors**	**Reasons Identified**

Fear about an uncertain future ahead	• Design doesn't have a great reputation of success and is related to low salaries and remaining jobless. This is due to the large number of graduates, mass produced by universities with little consideration of market needs and capacity. This uncertainty affects student motivation negatively.
Fear of failure and shock because reality does not match expectations	• Expectation when starting university is that Design is very simple and doesn't need much effort to succeed in it. This is caused by the wrong exposure to Art and Design during the primary school years, which is that Art and Design not taken seriously at all and many schools use the lesson time as a free class for pupils to eat, play and draw whatever they want.
Lack of general confidence when drawing or expressing new ideas	• Many students come from conservative religious family backgrounds where expressing too much confidence in general is viewed as a negative thing. Having original ideas or asking too many questions is also viewed negatively. Students are taught to follow mostly rules imposed by school, parents, society, and religion. This type of "dependent" personality trait can influence the student on many levels causing a biased and closed-minded thought process that inevitably affects creative thinking.
Believe that university is just an extension of school	• In school here in Jordan, much of the program is based on memorization and following rules, not on free-thinking and creativity. Some high-class private schools do offer a better program but are beyond the financial means of the majority of the population. So many students come to university thinking "what the teacher says must be memorized and repeated during an exam". Nothing more nothing less needed for to achieve the excellent score. This includes design students, which are even worse off than the students who go on to study science majors.
Fear of getting delayed with graduation if failing classes	• The longer a student remains a student the more expenses he is accumulating and delaying the opportunity to find work and this can be a problem for most students who are not well off financially.
Fear of having to pay again for the course if failing to pass	• Money issues are a big concern for many of the students.

Family attitude towards students starting a degree in design is not encouraging causing anxiety	• Respected disciplines in Jordan are considered Engineering and Medicine with Design ranking the lowest for most. If one goes off to study design it often means that the student was not accepted anywhere else due to low high school marks.
Studying design for purposes other than being interested in design	• Study with the intention to increase likelihood of marriage. • Study design as a means to obtain an "easy" certificate to enroll at a higher position in the army with a higher starting salary • It's considered better to study something rather than nothing if the high school marks are not good enough for any other field. • Study design because having transferred from another undergraduate field due to it "being too hard" • Study for to obtain "freedom" to meet friends and enjoy life away from family control.
There is a lot of competition among students	• However this in most cases does not translate into positive motivation to improve, but rather negative jealousy and attempts to find other easier ways to get better results and better scores. This may include paying for someone with more experience to complete the work for the student. This situation may also occur when the student faces failing the class but can't pass due to very low skill level and lack of understanding the class material.
Family pressure to study	• Not to go to university is considered shameful. Most families, even those who have a large number of kids and lack financial stability consider a university degree a must for all, even if someone doesn't really want to study.
Problems at home	• Overcrowded households, low income, family violence, having to work and study due to low income and/or lack of support, being married with children and studying at the same time, and other factors can exert a negative effect on student performance.

3. Observations & Discussion

Despite students entering higher education with very low level of skills in sketching and below average creativity, the courses in the curriculum are not designed to combat this weakness by offering enough content aimed at improving the basic skills of sketching and creative thinking before students embark on more advanced design classes (see Table 2 & Table 3). There are a few additional courses (that are not included as part of this study), which students take during the foundation year, but they too severely lack in teaching these basic skills, so weakness in these areas persists in many students till they graduate.

In addition by observing the performance of students on specific exercises, projects, and assignment tasks, that require sketching and drawing skills, as well as creativity, all students without exception who completed assignments, exercises, and projects, which contained sketching, technical drawing, and creativity as part of the requirements, scored always low on tasks that required sketching and creativity, while scoring much better on tasks that needed accurate technical drawing skills using drafting instruments (see Table 4). Even those students who scored high overall marks at the end of the semester, their lowest scores were consistently on tasks requiring sketching skills and creativity. A few students were observed that stood out from the rest (hundreds of other students), with very good technical drawing skills and much better overall sketching skills than the rest, but many of them still lacked in creativity and their sketching skills were always lower in comparison to their drawing skills. Also student scored extremely low grades in all three chosen foundation courses that have a practical aspect to them. Other, courses, and course sub-content, where students have to mainly memorize material, often results in better scores. However even though the student grade scores are extremely low, the reality of the situation is worse. Factors such as students dropping out due to low scores or absences have not been taken into consideration, or the fact that bonus points are granted sometimes to motivate students to work, or added at the end of the semester to move the overall curve up if the overall scores are way below an acceptable level. In addition some students are repeating courses having failed the first time, so their grades usually improve the second time they attempt a course. So for this reason, the numbers in the tables are to be used only as general indication of student level as many other factors influence the final score earned. However, in general most students range on the low to average, maximum reaching the Good level, very rarely the Very Good level and extremely rarely the excellent level. A further observation was that students ending up with a similar grade range do not mean that both share the same ability combinations. There are variations that differentiates one student from the other when it comes to sketching and technical drawing. A few combination "types" have not been encountered yet in any of the foundation classes taught by the author:

From the Fail - Pass Range (Student Type A, B1, B2) all combinations mentioned have been encountered From the Fair - Good Range (Student Type C1, C2, C3, D1, D2, D3, and D4) students with combination type (C3, D1, D3 and D4) have not been encountered.

From the Very Good - Excellent Range (Student Type E1, E2, E3, F1, F2, G1) students with combination type (E3, F2, and G1), have not been encountered. (See Table 4).

This indicates that there is a connection between sketching and technical drawing skill level to some degree. Even though they are different in many ways in their purpose and execution, they have some common ground. It was observed that when the student is reasonably good at sketching, they are always good at technical drawing as well, but the same is not true the other way round when the student is good at technical drawing, good sketching skills do not follow and the student may remain considerably weaker in this area. This is due to the fact that technical drawing is the more clear, defined method that can be learned more easily as long as the rules are followed, and the tools used help the student develop a good accurate drawing, while sketching is less clearly defined and is not usually applied in a step-by-step manner and requires good hand control skills and has many changing variables that can confuse the inexperienced student. In addition extreme situations such as when students are excellent in one and very bad on the other skill or students that are excellent in both areas have also not been encountered.

Based on the factors outlined affecting negatively the basic skills of novice students (see Table 5), the following is an outline of how these factors specifically translate to and affect the outcomes of the students in terms of freehand sketching, technical drawing, and creativity as observed in the classroom (see Table 6). In other words Table 6 shows how the seemingly unrelated factors observed in Table 5 can have direct effect on very specific ability to learn and perform. For example the believe that sketching is not a skill that is learnable

but based on inherited talent and that it is not important to have good sketching skills for a successful project can hamper many students from actually trying to explore and attempt to learn and improve the skill or they approach drawings fearfully and with a lack of motivation. So Table 6 attempts to translate general factors observed into specific points affecting basic skills directly.

Table 6 shows Sketching (in 2D and 3D), as well as Engineering drawing, and also Creativity, in addition to general problems affecting all three separately so that specific issues can be considered and addressed. Table 7 outlines the three main stages in the sketching process and Table 8 shows the steps to be followed during the third Stage of sketching (2D sketching - symmetric / asymmetric).

Table 6 Effect of the negative Factors depicted in Table 5 on specific student outcomes in regards to sketching, technical/engineering drawing, and creativity

<table>
<tr><th colspan="2">Freehand Sketching in 2D & 3D</th></tr>
<tr><td colspan="2">

The majority of students severely lack in sketching ability.
Students severely lack ability to judge scale and proportion, be it by directly looking and drawing real objects or by trying to draw by imagination or memory.
Severe lack of ability to draw without using a ruler and clear instructions to follow.
Extreme difficulty in understanding 3D space and sketching in perspective freehand causes major challenges. This problem however disappears in most student drawings when following accurate 3D drawing techniques using rulers such as the measuring perspective method or the revolved plan view.
Students are afraid to experiment and prefer to stay on the safe side, doing as little drawing as possible and exactly follow instructions.
Whenever students attempt to sketch they commence the sketch very carefully starting with the smallest details and decorations, using fearful small shaky lines, without planning out the paper, the size, or proportions, ending up with drawings that are either too small or too large not fitting into the page. Some students even draw using one and two point perspective at the same time, ending up with totally unrecognizable sketches, because they cannot see the difference between the two perspective methods or reason for their existence, and so believe combining them is acceptable.
When mistakes are pointed out to students many either fail to comprehend or see what is wrong in the drawing even when explained, and redrawn for them, and some become defensive insisting that their drawing are indeed “beautiful”, which they believe is the only goal of a sketch.
Students face in general fewer problems when sketching in 2D and understand Orthographic drawing easier, even when presented with progressively more difficult exercises. However this happens only when drawing an object they can observe and examine in front of them, not a new idea or object they have to envision in their minds.

</td></tr>
<tr><th>Eng. Drawing using Drafting Tools in 2D & 3D</th><th>Creativity</th></tr>
<tr><td>Most students are able to an acceptable to very good level to draw in 2D and even 3D when very clear step-by-step instructions are provided and when using rulers and measuring tools and where creativity is not involved, only copying a specific object from the board, following step-by-step instructions. In most projects once this stage has been reached and the “terrifying” sketching phase is behind, students become more confident in their abilities as observed by their behavior and drawings.</td><td>

When sketching to find new solutions, students are always copying and repeating designs from pictures or sketching by looking and drawing objects from their immediate surrounding. Some students even take a photo of an object, print it and then trace its outline and submit it as a creative new idea, or directly trace designed objects seen on the internet.
Most face extreme difficulty drawing from imagination. Even in rare situations where a student is creative (judged by their spoken explanation), they cannot express their idea visually due to poor sketching skills.
Students feel totally lost if not provided with very clear instructions to follow. Any vague ambiguous description or individual decision-making left to be made by the student creates total confusion and panic.

</td></tr>
<tr><th colspan="2">General problems affecting both

Sketching, Technical Drawing, and Creativity</th></tr>
</table>

- Overwhelmed quickly by information presented
- Unable to focus and concentrate for too long
- Unable to comprehend information or concepts that can have more than one option or correct answer, thus the purpose for sketching multiple concepts is not understood well, but students would normally present only one option. This also affects creativity as most students think there must be always a one and only solution, so the creative process is shut off before it even starts.
- Failing to comprehend or see what is wrong in the drawing even when explained, and redrawn for them, and some students become defensive insisting that their drawing are indeed "beautiful".
- Students face in general fewer problems when sketching in 2D and understand Orthographic drawing easier, even when presented with progressively more difficult exercises. However this happens only when drawing an object they can observe and examine in front of them, not a new idea or object they have to envision in their minds.

4. Results: Design & Implementation of Experimental Solution

Based on the points discussed in the previous section, and methods used to gather and analyze data, a possible preliminary intervention/solution will be designed. To do this the path-of-least-resistance principle and principle of least effort (**Performance Load**) will be used. It states that *"the greater the effort to accomplish a task, the less likely the task will be accomplished successfully"* (Lidwell W. & Holden K., Butler J, 2003). Performance Load can be of two types – Cognitive and Kinematic.Cognitive refers to the amount of mental effort needed to accomplish a task, while Kinematic refers to the amount of physical effort needed to accomplish a task (see Figure 1).

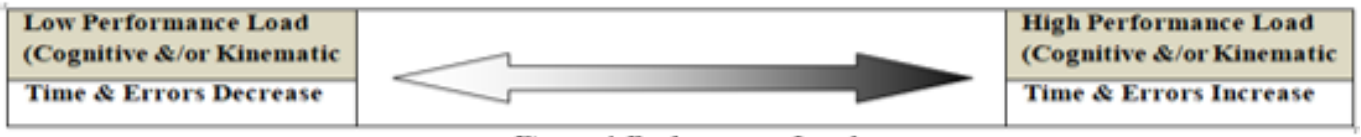

Figure 1 Performance Load

Applying Low Performance load is necessary because students with little experience or skills are involved. Designing processes and tools around low performance benefits all users, but the load must be low especially when dealing with inexperienced fearful novice students that are struggling with even the most basic tasks.

Low Performance load used in the designed solution is applied through the following:

- Clear simple to follow steps, (that may appear limiting, but also provide a possible base for creativity to develop at a later stage)
- Steps reduced to a minimum
- Easy to understand
- Dealing with one thing at a time (practice and then add one more thing, step-by-step without too much information overload)
- Focus on symmetrical abstract object profiles at first and asymmetrical profiles after that gradually increasing complexity.
- Focus on 2D sketching at first, increasing student confidence, rather than jumping straight to the more complex 3D sketching, allowing the possibility to draw in 3D sketching if needed and as skills develops.

The Experimental Solution includes Two Items:

- A – Sketching Tool
- B – Process.

When combined and integrated into foundation courses that need improvement in the two most problematic areas observed among students (Sketching and Creativity), it should assist students in developing these basic skills.

A. The Sketching Tool

The Tool should have a simple design, be easy to understand how to use, low cost, and also have diverse usability

while sketching using Lines and Angles, improve sketching skills as well as assist creativity, allow for flexibility in use and combine aspects of technical drawing into the sketching process to help bridge the severe mental and skill gap currently observed in the majority of students. Verstijnen et al., (1998), found through experiments that that mental imagery faces considerable difficulty in restructuring the initial conception of a pattern, and hence to discover new information in a mental image. *"The distinction of combining and restructuring throws new light on the issue of sketching. The combining process is easy to perform in mental imagery. The restructuring process is difficult to perform in mental imagery and is enhanced by sketching. That restructuring is the difficult part. The two processes of combining and restructuring together constitute important elements of the creative process"* Verstijnen et al., (1998). The tool together with the process should assist novice students facing these issues, especially the "restructuring" part of the sketching process which is essential for creative design.

Main Purpose and Explanation of the Sketching Tool

1. It serves as a subconscious link between technical drawing and sketching.

Currently students feel more confident with technical drawing and are able to perform better using tools. By providing a tool that can assist the sketching process it may alleviate some of the fears and anxiety associated with sketching, without affecting the essential purpose of the sketch.

2. Used for drawing straight lines and angles.

Drawing straight lines freehand takes a lot of practice and novice students cannot control their line-work successfully. When fast results are needed and not enough time to practice available to perfect lines, this tool can help but without the intervention of scales, numbers, and angles, so that students learn to judge shape and proportion and keep possibilities open without the limiting factors that drafting instruments through their accurate drawing purpose bring. Drawing straight lines and angles may also assist to form a structure of thinking that goes from simple/abstract to complex/detailed, rather than the opposite way round observed currently in how students sketch.

Basic Features of Tool and Explanation of how it may help improve sketching skill and creativity of the novice struggling student

The Shape

1. Simple without many details and features

This is important so that the attention remains on the sketch not the manipulation and understanding of how to use the tool and getting distracted in the process.

2. Designed to offer a balance between simplicity and diverse usability

It is important that the tool offers simplicity, however also enough possibility to draw diverse lines and angles in an easy & speedy way. In fact it has unlimited possibility depending on how it is used during the sketching process. The tool can be rotated in all directions or slide upwards, downwards, to the left, and right. Also the two side rulers placed on each and can rotate at 360degree. (See Figure 2). The starting position for sketching can be in 4 main ways (see Figure3). Figure4shows a few random configurations that can be used during sketching.

3. Provides for a limited number of line types to be used while sketching and allows for more variety if integrating tool with freehand sketching.

Even though the beauty of the sketch is in the many line types that can be used to give the sketch a lively dynamic appearance, the novice totally inexperienced student gets overwhelmed by all the vast possibilities available so is better to start with a limited number of line types – Light, medium, and heavy and using a constant line-weight.

4. Provides for creative experimentation

By allowing for experimentation through drawing lines and angles, it may distract the attention of the student from trying to copy an object to experimenting with abstract elements, which when put together form shapes without intentionally trying to draw anything specific. This is important for enhancing the creative outcome and breaks free from mind restrictions related to naming familiar objects in the mind and then trying to reproduce

an imitated version of them on paper. The mind should stay empty and open to all possibilities when starting a sketch. Using abstract basic elements such as lines and angles as starting point can help to make this transition to happen. In addition by allowing for creating decent looking lines using the tool, this can provide more confidence for the novice student and therefore willingness to continue experimentation, thus helping the creative process to develop, rather than anxiety to take over.

5. Helps to Improve Sketching skills.
Provides some help with improving line quality and stability, and integrity of shapes sketched when full freehand sketching is still too shaky and insecure. (See Figure 5). The tool through its design encourages some lines to be placed freehand while sketching, especially if sketching speed goes up, thus encouraging more freehand use in an incremental and less fear-inducing manner. The tool also helps in setting the ground of how to think about and approach a sketch, whether totally freehand or with the helping tool.

6. Provides for partial or full use.
Some lines can be drawn with the tool while others that are shorter and easier to control - freehand. When drawing freehand lines the tool serves as a guide to not get distracted by other elements and get carried away ending up with a shaky looking drawing. When the student feels confident enough they may use the tool just as general guide or for enhancing some hand-drawn lines.

7. Provides for easy drawing of symmetrical 2D object profiles, as well as 3D sketching when required.
Orthographic one-view symmetrical drawing gives clear straight-to-the-point information about the most important part of an object's shape (its silhouette) Only when students become more confident with the most basic type of sketching, attempts can be made for asymmetrical 2D sketching and after that 3D sketching. Distractions and detail that come with 3D sketching should be avoided at the start to not intimidate or slow-down the inexperienced student with too much information that can cause anxiety. In addition 3D drawing is challenging as it presents different information when changing the angle of view of the object, so the focus should be on 2D symmetric objects as a starting point until basics are mastered.

8. Provides through its stable middle area shaped as a cross (two lines intersected at 90 degree) a constant guide during sketching.
This is important for both 2D and 3D sketching starting point, especially for the extremely struggling students who end up with unrecognizable unstable appearing sketches.

9. Has no Scale & no Numbers.
This feature is important since its purpose it to form a bridge between freehand sketching and technical drawing, keeping the freedom of freehand sketching, and allowing training of subjective judgment of line-angle relationships and with it size and proportion (a skill needed in freehand sketching whether 2D or3D), and at the same time incorporates some of the benefits of accurate technical drawing.

The Main Material
1. Made of thin transparent Acrylic
This is important to not obscure the sketch on the paper and to not appear more important than the sketch itself, or to appear as a major guiding element of the sketch. Its purpose is only to help in forming the sketching not to stand out or draw too much attention on itself, therefore must remain as invisible as possible at the same time to be usable.

B. The Sketching Process
The tool alone is not enough if not accompanied by a clear step-by-step process to follow, clear explanation, and visual in-class demo with examples. It also needs observation of student application to make sure they understood what was explained.

Table 7 Stages in Sketching Process

Stage 1	Stage 2	Stage 3
It is important that the tasks at this stage do not cause any anxiety in students a) Drawing lines freehand. Only straight lines and a large number. b) Drawing freehand straight lines and dividing them into half's, quarters, and more parts correctly by visual judgement. c) Drawing random lines and intersecting them at different random angles. Any interesting results of abstract shapes should be outlined to stand out from the rest of the lines d) Drawing simple 2D geometric shapes freehand. For example squares of different sizes, rectangles and triangles starting with long intersecting lines, and circles and circle segments inside squares.	The tool is introduced as a support for the freehand sketch. A demo should visually show how to sketch using it and all its possibilities and advantages. The focus is on drawing 2D simple symmetrical abstract shapes. The three different line weights and their significance should be explained and shown.	**Sketching exercises using the tool entirely or as combination with hand drawn lines. Sketching exercises should be given without clearly naming what should be sketched. So for example not saying "draw a cup or bottle", but "sketch examples of shapes that may potentially become objects that can be used to drink from". Also emphasis should be on speed-drawing as much as possible, so that the hand will draw before the brain starts to over-think and limit the creative possibilities.** **All sketches should be 2D, showing the profiles of the objects. During the actual sketching process the following linear specific steps should be followed:** (See Table 8).

Table 8 Steps to follow during *Stage 3* (2D sketching - symmetric /asymmetric)

Sketch Type: 2D - Steps		Line Type: Length, Distance from other Lines	Line Type: Straight/ Curved	Line Type: Light/ Medium/ Heavy	Angles	Other
1	**Drawing Lines using tool**	Free, & longer that may be required.	Straight	Light Uniform weight	Only Parallel Lines or intersecting at 90 degrees. Define center-line. What you draw on one side you must draw the same mirrored on the other if drawing symmetric sketch.	Rubber use not allowed
2	**Drawing Lines using tool**	Free, & longer than may be required.	Straight	Light Uniform weight	Using lines at different angles to intersect the vertical and horizontal lines	Rubber use not allowed
3	**Adding More Lines as needed using tool**	Free	Straight	Light Uniform weight	Using lines at different angles to intersect the vertical and horizontal lines to form smaller details.	Rubber use not allowed
4	**Trans-forming Lines**	Based on already drawn lines and intersections	Curves, circle segments (freehand)	Light Uniform weight	No Angles, freeform curves or circle segments symmetric from both sides	Rubber use not allowed. Keep all construction lines

5	**Finalizing the sketch**	Based on already drawn lines and curves and circle segments	Drawing over existing lines (no new lines added). Final Contour Lines of Shape Defined	Medium (for the ground & center line) Heavy (for the outline of finished object. Uniform weight	Based on already drawn angles. Nothing new added or modified at this stage.	Rubber use not allowed. Keep all lines. Only line weight to be manipulated
6	**Repeat Steps 1-5 and come up with a new sketch by changing the proportions and size of the lines and changing the angles**					
7	**Repeat Steps 1-5 but now focus on creating a variety of Asymmetrical 2D abstract objects.**					
8	**Attempt a simple real design exercise showing a variety of 2D designed profile options as shape solutions to a specific problem given**					

In summary what makes this tool original is in its very specific design outlined in detail in Section 4 and illustrated in Figure 2 & 3. This together with the process outlined when employed together during the sketching phase of a project, will help to bridge the gap between sketching and engineering drawing merging the two (which the research indicated is necessary), and thus helping the students who have very low skill level in sketching but much better skills in engineering drawing, to improve and to encourage exploration during the phase they struggle with, and to help them deliver better results in terms of range of concepts and quality and creativity.

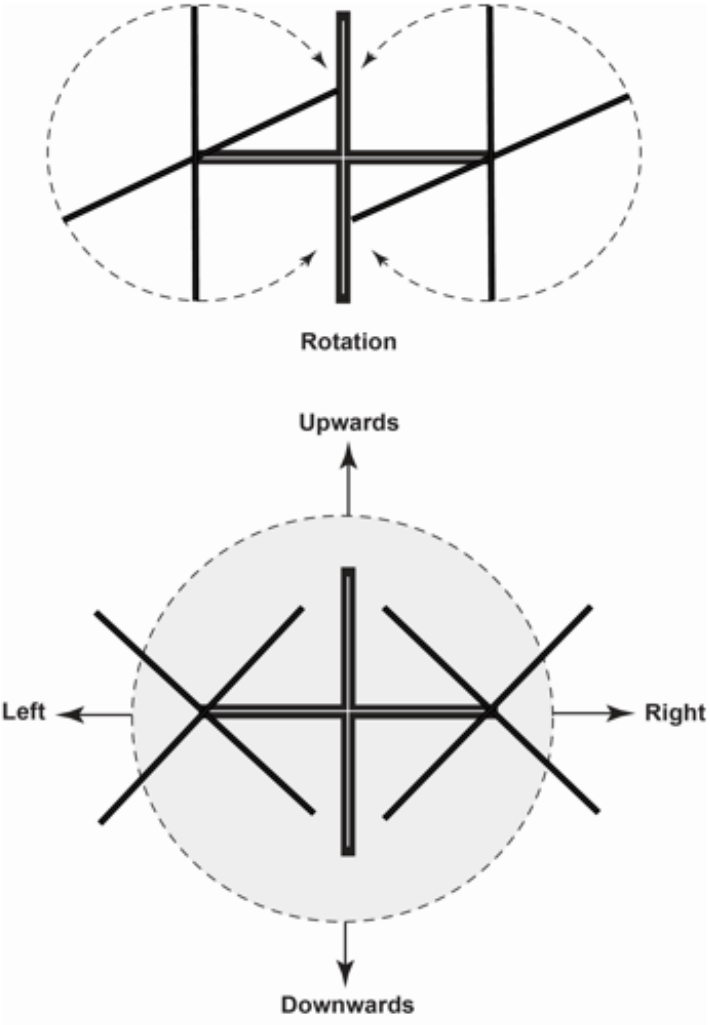

Figure 2 Tool's Rotation and Movement capabilities

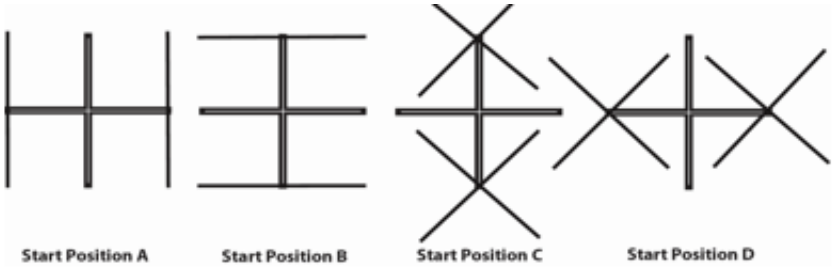

Figure 3 Tool's main Starting Positions for Sketching

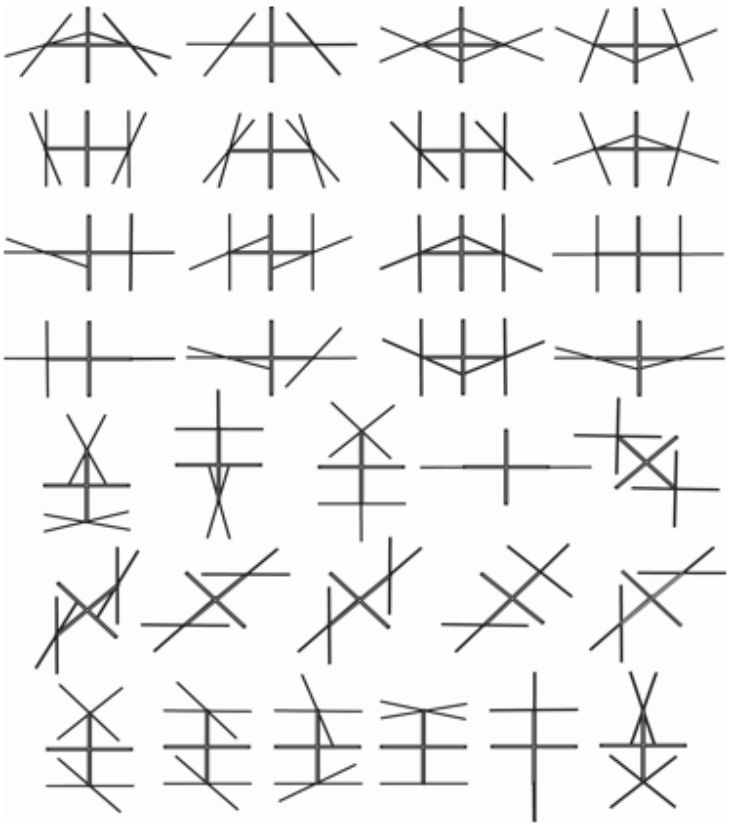

Figure 4 Examples of random configurations that can be used during sketching. Possibilities are limitless

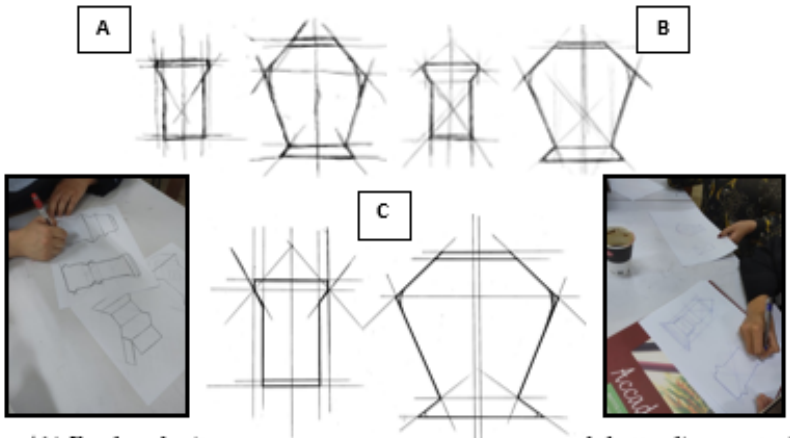

Figure 5 Drawing (A) Freehand with bad line control, (B) Freehand with better line control, and (C) Us bad line control but with the tool. The two images are examples of students drawing during the exerci

5. Limitations, Further Research, and Conclusions

This study investigated, gathered, and analyzed the reasons behind the severe lack of essential sketching skills and low creativity observed among an overwhelming number of students during their foundation year of study and attempted to design and develop a possible intervention/solution to aid this deficit among multiple external and internal constraints currently taking place. Due to the complex multifaceted nature of the problem, there can be no one simple answer or solution that can eradicate the problem or bring about drastic improvements in a short period of time. The constraints of the current curriculum & the limited opportunity for its modifications or changing course content, severely limits the range of possibilities. In addition cultural, social, economic, psychological, and other hard-to-modify factors exert a great deal of influence on all student behavior and thinking. Within all current limitations, a holistic view with practical implications had to be taken by developing a process and tool to support and attempt to improve the most problematic areas of the novice students – the severe lack of sketching skills & creativity, which have a great impact on the overall success as designers and product developers. The current study points towards the idea that merging elements of technical drawing (with which students feel more comfortable and confident and show higher ability), with the sketching process, could be one way to reduce the anxiety and uncertainty connected with sketching and aid in alleviating some of the current challenges faced by students in terms of lack of skill and also aid indirectly in creative thinking and desire for experimentation. The process and tool described in this study may benefit students of very low skill level but may slow down students of more advanced skill level. This may be a limitation, however considering that the majority of students accepted each semester into the design program at YU fall mostly into the very low-skill category with extreme difficulty in all areas of study, especially sketching and creativity, solving the problems of these students remains currently a priority. Preliminary user testing using a prototype and a few participants shows promising improvements taking place. However more precise user testing with more participants that fit the criteria and over a longer period of time is necessary for future refinement.

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