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Exploring the Relationships between Artistic Creativity and Innovation Attitudes in Engineering Students

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Abstract

This research explored potential relationships between the innovation self-efficacy (ISE) of engineering students and their artistic creativity and life experiences revealed on an ice-breaker assignment. In a community-building assignment, students were directed to introduce themselves through cartoon monster drawings that communicated various personal attributes (such as the number of languages they speak, and the number of states visited). Previous research has found that multicultural experiences can shape feelings of self-efficacy concerning innovation and creativity. This pilot study was conducted in a single junior-level course for environmental engineering students. The innovation self-efficacy of participants was measured using a survey that included items from the Very Brief Innovation Self-Efficacy scale (ISE.6), the Innovation Interests scale (INI), and the Career Goals: Innovative Work scale (IW). The drawings were analyzed for Artistic Effort (AE) and Creative Work (CW) by engineering and art evaluators, respectively. The ISE survey results were compared with the AE and CW scores and the correlations with travel, gender, and multilingualism on creativity attributes were explored. A strong correlation between CW scores and AE scores was observed. A negative correlation between CW and ISE.6 was found. The CW scores were significantly different between female and male students, except for black/white shading in the cartoon drawings. There were no significant differences between the AE scores for female versus male students. Our results do not support the existence of a correlation between multilingualism and travel with artistic creativity and innovation self-efficacy attributes. Overall, we did not find that the students' artistic creativity or life experiences revealed through the self-portrait activity provided insights into innovation attitudes.

Introduction

Creativity and innovation are crucial skills for engineers, as they enable the development of novel solutions to complex problems and drive technological advancements [1-4]. The National Academy of Engineering (NAE) in the United States has emphasized the need for engineers to possess not only technical skills but also creativity and innovation to address global challenges and create new opportunities [5-6]. Despite the importance of creativity and innovation in engineering, there is evidence of decreasing creativity and critical thinking in senior engineering students [7-8]. Previous studies collectively emphasize the dynamic nature of creative confidence and its interplay with training and past creative achievements [9-13]. Additionally, a meta-analysis revealed a strong correlation between self-rated creativity and self-efficacy, indicating the significant influence of self-efficacy on creativity [14]. It seems the lack of confidence in creativity among engineering students is a complex issue influenced by factors such as self-efficacy, training, past achievements, and the dynamic interplay between self-confidence and creativity. Addressing this issue requires a multifaceted approach that considers the psychological, educational, and experiential aspects of fostering creative confidence among engineering students.

The literature has also identified lower self-efficacy of female students in various STEM domains, which contributes to the low representation of female students in STEM [15]. Studies have identified gender differences in creativity [16] and creativity anxiety was also found to be pronounced in women [17]. A large study across many cultures found that adults' confidence in innovation was statistically higher for men than women, but the difference was so small as to be negligible [18]. Charyton and Snelbecker's study also did not find differences between male and female engineering and music students in scientific or artistic creativity [19]. Gender, age, and specialization within majors also yielded no significant differences in creativity [19].

Life experiences may impact creativity and innovation. For example, living abroad is associated with higher levels of creativity while time spent traveling abroad did not have a significant impact on creative insight [20-23]. On the other hand, experiences traveling to many different countries seem to increase individuals' general sense of trust in humanity [22], and travel experiences may contribute to the development of adaptive and creative abilities [24]. Research has also suggested that multilingualism can foster creativity [25-27], including traits such as open-mindedness and intrinsic motivation [28-31] and the capacity to produce original, creative ideas, particularly in verbal domains [30-32].

It is uncertain whether students' artistic creativity will be correlated in any way with their engineering innovation self-efficacy or interests. Previous research has found correlations among different measures of creativity for engineering students through the Creativity Personality Scale, Creativity Temperament Scale, Cognitive Risk Tolerance Scale, and the Purdue Creativity Test [33]. Another approach assessed students' confidence in innovative design through a 5-item Innovation Self-Efficacy (ISE5) scale, a 4-item Innovation Interests (INI) scale, and the 6-item Career Goals: Innovative Work (IW) scale [34]. It seems that the lack of confidence in creativity among engineering students is a complex issue influenced by factors such as self-efficacy, life experiences, training, past achievements, and the dynamic interplay between self-confidence and creativity. Our exploratory research aims to understand the impact of travel, gender, and multilingualism on artistic creativity and the ISE attribute scores (ISE: Innovation Self-Efficacy, INI: Innovative Interest, and CGWI: Innovative Work Interest) of engineering students.

Research Questions

This research aims to answer the following three research questions:

1. Does engineering student artistic creativity correlate with Innovation Self-Efficacy attributes (ISE, INI, IW)?
2. Do the artistic creativity and ISE attributes (ISE, INI, IW) differ between female and male students?)
3. Do multilingualism and travel correlate with artistic creativity and ISE attributes (ISE, INI, IW)?

Methods

This research was conducted under a protocol approved by the Institutional Review Board at the University of Colorado Boulder (protocol # 23-0388). Students enrolled in a Water Chemistry course in fall 2023 were invited to participate in the study. Most students were juniors or seniors majoring in environmental or civil engineering. In the first week of the semester, students were given an assignment to draw themselves as a cartoon monster and post their drawing to a discussion board (full instructions in Appendix A). The assignment was meant to act as an icebreaker and facilitate teamwork. The assignment directs students to include attributes like the number of states stepped in and languages spoken through parts of their monsters like the legs and mouths, respectively. Additionally, the students could include flags to represent heritage or countries visited. Figure 1 shows two examples of student drawings.

Students consenting to participate in the research allowed their drawings to be evaluated for creativity and completed a survey at the beginning of the semester. The survey presented students with 15 statements which they rated on a one to seven scale (seven being extremely confident, very high interest, and extremely important). These questions measured innovation self-efficacy (ISE) using the Very Brief Innovation Self-Efficacy scale, innovation interest (INI) using the Innovation Interests scale, and innovative work goals using the Career Goals: Innovative Work scale (IW) (adapted from [34-35]).

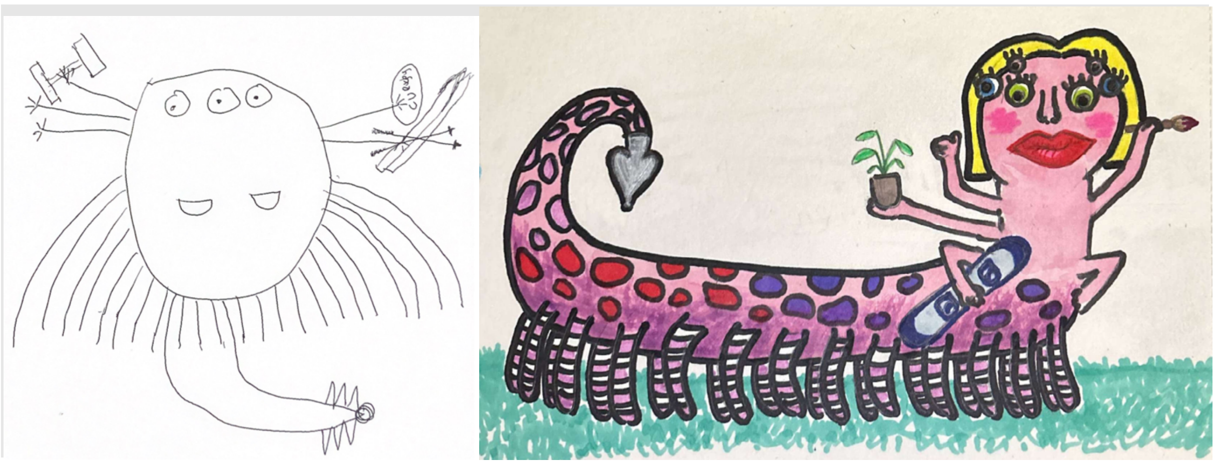

Figure 1. Example Monster Drawings (left and right rated lower and higher on creative work, respectively)

The specific survey items are shown in Appendix B. The survey concluded with demographic questions on gender, race, and whether the student identifies as neurodivergent. The students chose whether to receive in-class extra credit or compensation in a $10 gift card; students not participating in the research could complete an alternative short writing assignment to receive extra credit. Study participants were assigned an ID code given by the second author. This was done because the first author was also the instructor for the water chemistry class. The ID codes allowed the author to analyze the data while providing her students with full anonymity.

The drawings underwent analysis for artistic creativity using two methods: 1) a Creative Work (CW) rubric employed by an art professional, and 2) an Artistic Effort (AE) rubric developed by the engineering team.

1- Creative Work (CW) employed by an art professional: It is important to note that creativity in art can vary across different disciplines, such as visual arts, music, and dance, and therefore, the measurement of creativity needs to consider the specific domain content [36-37]. A Fine Arts professor at the University of Colorado Boulder's Art and Art History Department employed a widely used rubric for assessing creative work in their field to evaluate each drawing (Table 1). This rubric combines the J. Paul Getty Museum's standards for the Elements of Art for teachers [38], which include line, color, proportion/perspective (replacing space), balance/uniformity (replacing form), with additional criteria added by faculty over the years. These additional criteria aim to level the playing field for students who may not be naturally gifted in drawing or art, focusing on elements such as time, dedication, ambition, technique, experimentation, and concept. The CW rubric comprises ten categories (see Table 1, CW category) and was rated on a scale from one to ten. All categories were of equal weight in scoring. The final score (out of 100 in Table 3 or the Results section) was rescaled to seven to facilitate a meaningful comparison between the fine arts faculty's ratings and the ISE scores.

Table 1. Comparison of the fine arts professor and engineering students' ratings of creative work (CW) and artistic effort (AE).

Creative Work (CW) Category	CW rated by Fine Arts Professor Average (1-10)	Artistic Effort (AE) Category	AE rated by Engineering Team Average (0-2)
Line / mark making	5.6 (3-9)	NR	NR
Time / dedication	6.2 (3-10)	Dedication	1.1 (0-2)
Proportion / perspective	3.5 (1-8)	NR	NR
Balance / uniformity	7.4 (5-10)	NR	NR
Use of color / value	6.3 (0-10)	Use of color	0.8 (0-2)
Black / white shading	6.1 (5-10)	NR	NR
Ambition	5.7 (1-10)	Inspirational (ambition)	1 (0-2)
Craft / technique	5.8 (1-10)	Skill (craft/technique)	1.2 (0-2)
Experimentation	6.7 (3-10)	NR	NR
Concept / overall design	6.9 (3-10)	Concept / overall design	1 (0-2)
Total (raw score)	60.3 (35-88)	NR	NR

NR = not rated by the engineering team.

2- Artistic Effort (AE) developed by the engineering team: This scale offered an engineering perspective to artistic creativity. Three undergraduate research assistants completing degrees in engineering and applied math scored the drawings to assess the perceived artistic effort in each. The research assistants' assessment focused on the perceived artistic effort rather than the actual skill level of the drawings. The students devised a rubric with five subparts: use of color, concept/overall design, inspirational (ambition), dedication, and skill (craft/technique). These criteria were established after brainstorming ways to identify increased effort. While the use of color was not a specific requirement of the assignment, it was considered an important medium for self-expression that breathed life into the self-portrait monsters. The ability to identify a cohesive vision for the monster was deemed impressive and was included in the evaluation. Many students demonstrated a desire to create something unique or interesting, and while execution was not always perfect, the attempts were rewarded for showing effort beyond the assignment requirements. Evaluating the concept and inspiration behind the design aimed to assess how contemplative students were during the assignment. The engineering team also sought to recognize participants who invested more time into the assignment than others, as this often reflected in the quality of the drawing. The rubric categories were chosen based on the engineering team's past experiences having their artistic work graded by art professionals and looking at how their previous teachers assessed overall creativity and perceived effort in their work. Each category was rated as a 0, 1, or 2. After reviewing the art professor's categories (described in Table 1 under AE categories in parentheses), two categories in the rubric were renamed. The engineering team's three individual scores were averaged and reported in Table 1. The total AE scores were rescaled to a seven-point scale in Table 3 to enable a meaningful comparison with the Innovation Self-Efficacy (ISE) scores.

For comparison by gender among the scores assigned to the drawings and survey responses, t-tests were conducted in Excel. Statistically significant differences were inferred for p-values below 0.05. To explore correlations among the factors (such as the creativity scores assigned to the drawings and the innovation survey scores) the non-parametric Spearman's rho was calculated. As a rule of thumb correlation values below 0.2 are not significant, 0.2-0.4 weakly correlated, 0.4-0.6 moderately correlated, and above 0.6 strongly correlated. The statistical significance of the correlations was also reported.

Results

RQ1 Artistic Expression versus Quantitative Scores

Table 2 summarizes the range of each of the quantitative scores for creative work (CW), artistic effort (AE), and survey results on Innovation Self-efficacy (ISE), Innovation Interests (INI), and Career Goals-Innovative Work (IW). Table 3 shows the results for correlations among these values. There was a strong correlation between the creativity scores of the student drawings from the Fine Arts faculty member (CW scores) and engineering team (AE scores), as would be expected. There were also some weak to moderate correlations among the three innovation constructs: innovation self-efficacy, innovation interest, and innovative work. There was a surprising inverse relationship between the creative work scores and students' innovation self-efficacy. The student artistic effort scores were not correlated with ISE, INI, and IW.

Table 2. Characteristics of student scores (n=37; scaled to max of 7).

Parameter	Creative Work (CW)	Artistic Effort (AE)	Innovation Self-efficacy (ISE)	Innovation Interests (INI)	Career Goals - Innovative Work (IW)
Avg score	4.12	4.33	4.02	5.18	5.03
Median score	4.34	3.97	4.00	5.20	5.00
Std Deviation	1.26	1.20	0.90	0.81	0.93
Range	2.1-6.15	2.1 - 6.77	2.40 - 6.00	3.40-7.00	3.67-6.50

Table 3. Correlation matrix for CW, AE, ISE, INI, and IW.

Parameter	Creative Work (CW)	Artistic Effort (AE)	Innovation Self-efficacy (ISE)	Innovation Interests (INI)	Career Goals - Innovative Work (IW)
CW	1	0.634**	-0.383*	0.022	-0.022
AE	0.634**	1	-0.057	0.117	0.137
ISE	-0.383*	-0.057	1	0.322^	0.273
INI	0.022	0.117	0.322^	1	0.425*
IW	-0.022	0.137	0.273	0.425*	1

Statistical significance: ** $p < 0.001$, * $p < 0.05$, ^ $p < 0.10$

RQ2: Gender Difference in Artistic Expression and Innovation Self-Efficacy

The artistic creativity scores assigned by the Fine Arts faculty to students' drawings (CW scores) were significantly different between female and male students overall and for all of the sub-categories except black/white shading (see Table 4). Female students' drawings had higher creativity scores. There were no significant differences between the total artistic effort (AE) scores assigned by the students for female versus male students.

Table 4. Comparison of creative work (CW) scores and artistic effort (AE) scores by gender.

Creative Work (CW) Category	Fine Arts Faculty Ratings Average (stdev)	
	Female (n=21)	Male (n=15)
Line / mark making	6.0 (1.1)**	5.1 (0.7)
Time / dedication	6.7 (1.6)*	5.5 (1.1)
Proportion / perspective	4.6 (2.2)**	2.1 (1.5)
Balance / uniformity	8.2 (1.8)**	6.4 (1.6)
Use of color / value	7.2 (1.4)**	5.1 (1.7)
Black/white shading	6.4 (1.7)	5.8 (1.2)
Ambition	7.0 (2.2)**	4.1 (2.3)
Craft / technique	7.0 (2.2)**	4.1 (2.4)
Experimentation	7.4 (1.7)**	5.6 (1.9)
Concept / overall design	7.9 (1.7)**	5.5 (2.4)
Total (raw score)	68.5 (13.7)**	49.4 (14.1)
Student AE (out of 10)	6.4 (1.6)	5.7 (1.9)

t-test: ** $p < 0.01$, * $p < 0.05$

Female students had lower innovation self-efficacy than male students (female average 3.7 ± 0.9 vs. Male 4.3 ± 0.6, p 0.04). There were no significant differences between innovation interests or innovative work between female and male students (p 0.40 and 0 0.52, respectively).

When the correlation results were separately analyzed for female and male students, there was a weak negative correlation of creative work (CW) scores with ISE for female students (rho -0.32, p 0.15), although the result does not meet normal statistical cut-offs for significance. There was not a correlation of CW with ISE for male students (rho -0.19, p 0.488.) A new result emerged which was a moderate to weak correlation of male creative work (CW) scores with innovative work interest (IW) (Pearson 0.496; Spearman rho 0.353, p 0.1975).

RQ3. Multilingualism and Travel in Creative Work and Innovation Self-Efficacy

There was no significant variation in the number of languages spoken by the students (24 spoke one language, 11 two languages, and 2 students three languages). For the number of states that the students had set foot in (excluding air travel layovers), the range was 2 to 32 (average 17, standard deviation 7). The number of languages spoken and states visited were inversely correlated (Spearman rho –0.387, $p < 0.05$). Grouping the students into those speaking only 1 language and comparing them to those speaking two or more languages also illustrates the lower average number of states visited for those speaking more languages, but little to no clear differences in innovation attitudes (Table 5). As depicted in Table 6, neither the number of languages nor the number of states visited were significantly correlated with innovation self-efficacy attributes (i.e., ISE, INI, and IW) or creative work (CW).

Table 5. The number of languages spoken by students versus the average number of states visited and average innovation self-efficacy attribute scores (ISE, INI, and IW); standard deviation is also shown.

Number of Languages Spoken	n students	Number of States Visited	Creative Work (CW)	ISE	INI	IW
1	24	19 ± 7	3.9 ± 1.3	4.1 ± 1.0	5.1 ± 0.7	5.0 ± 0.9
2+	13	13 ± 6	4.5 ± 1.2	3.9 ± 0.8	5.4 ± 0.9	5.1 ± 0.9

Table 6. Correlation coefficients between languages, number of states visited, and innovation attributes (none with $p < 0.1$).

Parameter	ISE	INI	IW	CW
Languages	-0.18531	0.03077	-0.0302	0.12874
States Visited	-0.02186	0.24125	0.15738	-0.10382

Limitations

The first limitation is the small size of the dataset. This is particularly limiting when examining statistical significance indicators, such as using typical thresholds for Type 1 errors. Thus, the results should be considered exploratory to identify potential effects for further study. A second limitation is the nature of the monsters assignment as an icebreaker activity, where students would opt to devote varying levels of effort. In addition, because students knew the drawings would be posted on a discussion board, the public-facing element may have spurred or limited students' desire to be creative in their drawings. Innovation self-efficacy and interest do not measure actual innovation ability. Another limitation is the exploratory nature of the artistic effort (AE) rubric developed by the engineering team, in contrast to the established rubric utilized in the Fine Arts to assess creative work.

Discussion

This research found an inverse relationship between a student's artistic creativity in an open-ended icebreaker activity to draw a self-portrait cartoon monster and their innovation self-efficacy (ISE). The results indicate that engineering types of innovation are very different than artistic creativity. It may be that students who evidenced artistic creativity when they were younger were discouraged from pursuing an engineering major in college, and/or that more creative students left engineering before junior year (the lower end of students enrolled in the water chemistry course). In addition, artistic creativity was demonstrated by drawings while innovation was self-rated by the research participants.

The negative correlation between creative work (CW) scores and innovation self-efficacy (ISE) appeared stronger among female compared to male students. Female students had higher creative work scores and lower innovation self-efficacy scores than male students, on average. These results indicate that creativity and innovation might tend to manifest differently in female as compared to male engineering students. This result seems analogous to literature findings [39-40]. Further, the lower innovation self-efficacy for female students seems congruent with the larger creativity anxiety found by Daker et al. [17].

No relationships were found between the innovation scales and the ability to speak multiple languages. We note that the variation in language number across the dataset was small and does not reflect the level of competence in multiple languages. Some students may have been raised bilingual while others may have had a couple of years of formal schooling in a second language, for example. Nevertheless, as stated in the introduction, the body of research suggests that multilingualism may positively impact cognitive flexibility, original thinking, and creative problem-solving abilities.

The inverse relationship between number of languages spoken and number of states visited may reflect international students or students who traveled internationally rather than widely across the U.S. This was supported when looking at whether or not the drawings included the flags of different countries – drawings with no flags averaged 1.1 languages spoken while drawings with 1 or more flags averaged 1.9 languages spoken. Drawings with no flags averaged 18.4 states visited versus drawings with flags averaging 14.6 states visited.

A lack of relationship between the number of states visited and creativity or innovation measures may reflect the fact that for many undergraduates their travel may have been related to the interests of their parents. Their travels may have been more tourist-driven, and if the students stayed in chain hotels and ate in chain restaurants found across the U.S. their experiences of different cultures may have been quite limited. Overall, the literature supports our observation that living abroad and immersive foreign experiences may have a more significant impact on creativity compared to merely traveling abroad. The findings also indicate that the impact of travel on creativity may vary based on the depth of cultural immersion and the diversity of travel experiences.

Future Work

In our study, the artistic creativity of the research participants was demonstrated through a drawing while their innovation was evaluated by a self-rated measure. In our future work, we envision assessing research participants' term projects for innovation demonstrated through their work. This would provide us with more comparable measures for artistic creativity and innovation self-efficacy attributes. Our future focus group with the research participants will explore the portion of states that they reported having visited that they also lived in. This can help us better understand the relationship between the lived experiences of the participants with their artistic creativity.

Summary and Conclusions

This research explored the correlation of engineering students' innovation attitudes and artistic creativity with gender, travel, and multilingualism. The innovation self-efficacy of participants was measured using the Very Brief Innovation Self-Efficacy scale (ISE.6), the Innovation Interests scale (INI), and the Career Goals: Innovative Work scale (IW). The drawings were analyzed for artistic effort (AE) and creative work (CW) by an engineering team and a fine arts professor, respectively. The ISE survey results were compared with AE and CW scores and the correlations of gender, travel, and multilingualism with creativity attributes were explored. A strong correlation between CW scores and AE scores was observed. The CW scores were significantly different between female and male students, except for black/white shading. There were no significant differences between the AE scores for female versus male students. There was a negative correlation between CW and ISE scores. A correlation between multilingualism and travel with artistic creativity and ISE attributes could not be established. The results illustrate that there are significant differences between artistic creativity and innovation attitudes in engineering students.

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APPENDIX A

Meet the Monsters!

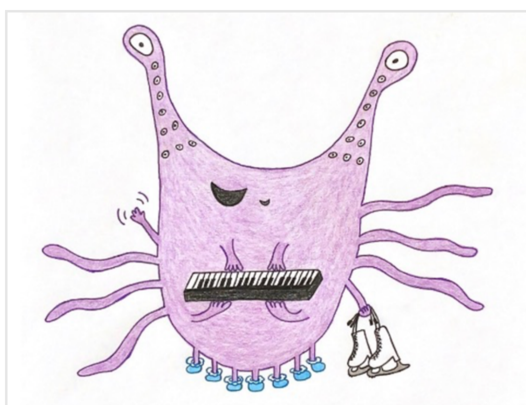
Let's get to know each other and have fun while doing it!

Imagineer yourself as a monster! How would you look like (examples below)? Make sure your monster has the following body parts:

- **leg(s)**: number of states you have stepped in (flying over and airport standby does not count)
- **mouth(s)**: number languages you speak
- **eye(s)**: number episodes/movies you watched (e.g., on Netflix) this weekend
- **hand(s)**: number of courses you have this semester
- **tail(s)**: number of pets you have
- **in your hand**: hold an object that is your hobby, job or sport that you play, any CU clubs that you are part of, flags of international travels.
- **optional**: situate your monster in a background that represents the strengths you received from your family (e.g., the environment you grew up in, skills passed on to you by your family, a family business, heritage, or traditions).

When done, take a photo of your piece of art and upload it here on the discussion board by the specified deadline. Then you have two days to review your classmate's monsters and make 2 comments.

Your instructional team (including me!) will also create their own monsters and will share them with the class. An example of a monster by my former student (current practicing engineer) is below:



Adapted from: Riley, J. (2018, August 8–11). Making the Most of the First Day of Your Class. [Conference presentation]. Lily Conference 2018, Austin, TX, United States.

APPENDIX B

Innovation Self-efficacy survey questions

Please think about how confident you are in your ability to do these activities. How confident are you in your ability to ...	How much interest do you have in...	How important is it to you to be involved in the following job or work activities in the first five years after you graduate?
Ask a lot of questions.	Experimenting in order to find new ideas.	Searching out new technologies, processes, techniques, and/or product ideas.
Generate new ideas by observing the world.	Conducting basic research on phenomenon in order to create knowledge.	Generating creative ideas.
Finding resources to bring new ideas to life.	Developing plans and schedules to implement new ideas.	Promoting and championing ideas to others.
Connect concepts and ideas that appear, at first glance, to be unconnected.	Giving an elevator pitch or presentation to a panel of judges about a new product or business idea.	Investigating and securing resources needed to implement new ideas
Experiment as a way to understand how things work.	Build a large network of contacts with whom you can interact to get ideas for new products or services.	Developing adequate plans and schedules for the implementation of new ideas.
		Selling a product or service in the marketplace.