Complex Engineering Problem and Outcome-based Engineering Education:

A Case Study

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ABEEK. KSME

BAETE Symposium
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CONTENTS

Higher Education in Korea

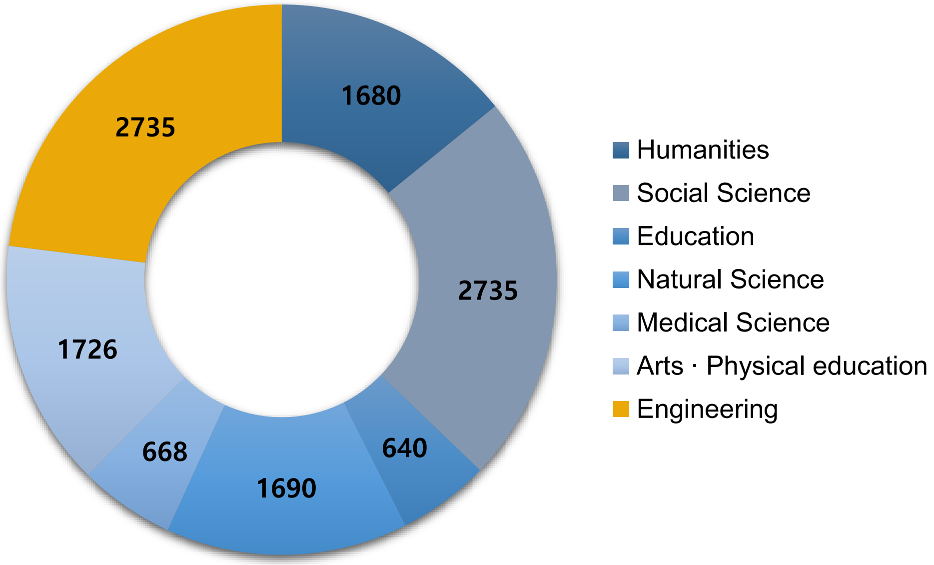
(Source: Korea Education Statistics Service, 2017)

⊕ Statistics on Higher Education in Korea

No. of Universities	No. of Programs	No. of Students
189	11,874	2,050,619 (564,952 in Engineering)
No. of Faculties	Size of Entry Cohort	No. of Graduates
73,326	343,076	335,367

⊕ Number & Percentage of Engineering Programs

Humanities	1680
Social Science	2735
Education	640
Natural Science	1690
Medical Science	668
Arts · Physical education	1726
Engineering	2735
Total	11,874



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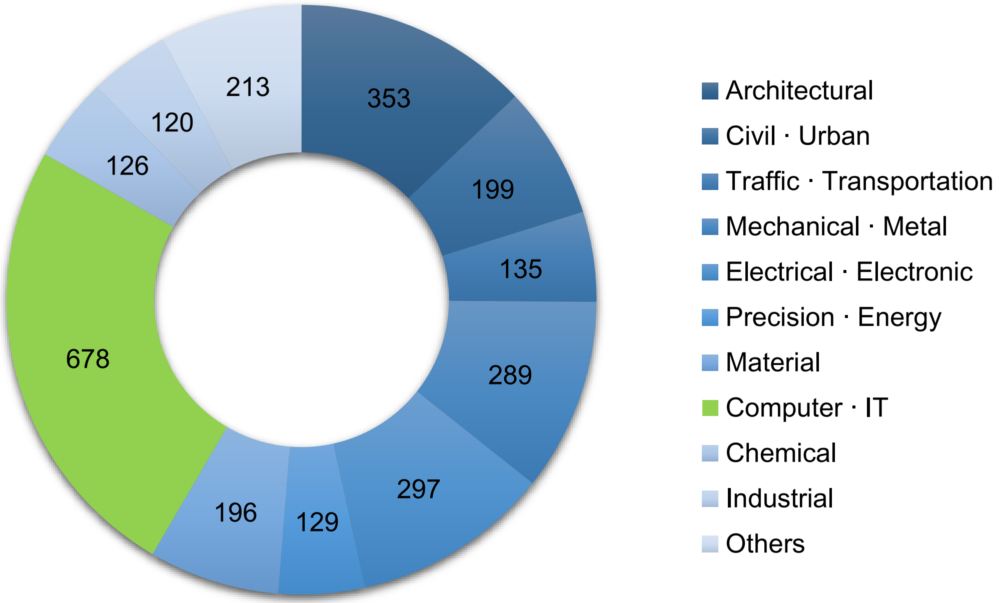
Engineering Education in Korea

(Source: Korea Education Statistics Service, 2017)

⊕ Breakdown of Engineering Programs

Architectural	353
Civil · Urban	199
Traffic · Transportation	135
Mechanical · Metal	**196**
Electrical · Electronic	297
Precision · Energy	129
Material	196
Computer · IT	678
Chemical	126
Industrial	120
Others	213
Total	2735



Accreditation Board for Engineering Education of Korea (ABEEK)

- Non-profit, independent body founded in 1999
  - Engineering → Washington Accord in 2007
  - Computer and IT → Seoul Accord in 2008
  - Engineering Technology → Sydney and Dublin Accords in 2013
  - Only recognized accrediting body in engineering

- Major industries, engineering societies, and public institutions in the governing board

- Accredited Programs (2019)
  - Engineering: 425 programs at 80 universities
  - Computer and IT: 50 programs at 41 universities
  - Approx. 50% of universities in Korea

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Impact of Accreditation on Engineering Education

- Outcome-based education, Program Constituencies, CQI
- Math, Basic Sciences, Computing
- Soft skills
- Engineering design
  → open-ended problem
  → teamwork, communication skills
- In 2015, *complex engineering problem* embedded in ABEEK graduate attributes (KEC2015)
  → ABEEK mandates capstone design to solve complex engineering problem

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ABEEK Graduate Attributes (KEC2015)

(1) An ability to apply knowledge of mathematics, basic sciences, engineering, and information technology to the solution of complex engineering problems

(2) an ability to analyze data, and verify facts and hypotheses through experiments

(3) an ability to define and formulate complex engineering problems

(4) an ability to apply latest information, research-based knowledge and appropriate tools to the solution of complex engineering problems

(5) an ability to design a system, component, or process to meet desired needs within realistic constraints

(6) an ability to contribute to project team output in the solution of complex engineering problems

(7) an ability to communicate effectively under diverse situations

(8) an ability to understand the impact of engineering solutions in the context of health and safety, economics, environment and sustainability

(9) an ability to understand professional ethics and social responsibilities

(10) a recognition of the need for, and an ability to engage in life-long learning in the context of technological change

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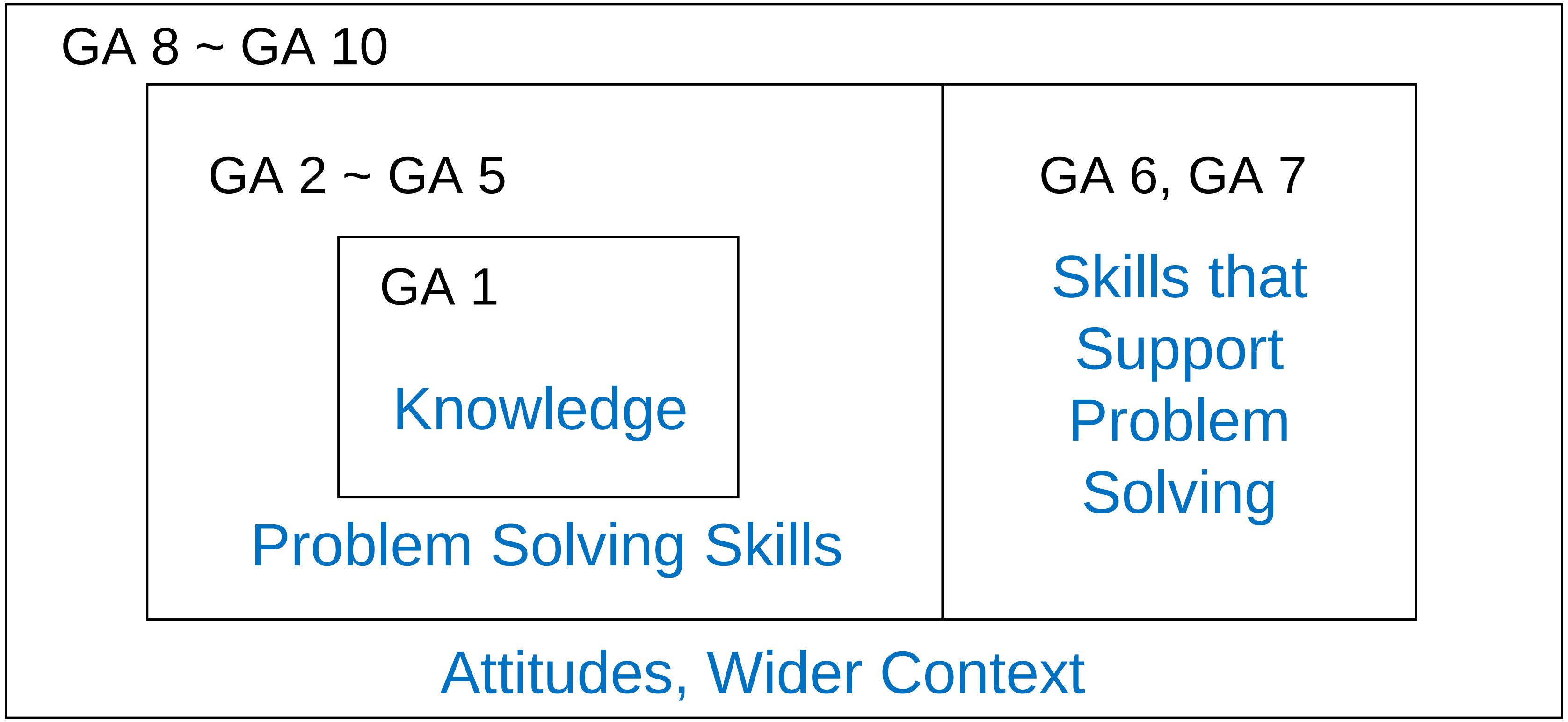
ABEEK Graduate Attributes Framework

- Categories

1. Applying Knowledge (GA1)
2. Problem Solving: Experiment, Modeling, Tools, Design (GA2~GA5)
3. Teamwork & Communication (GA6, GA7)
4. Attitudes, Understanding Impact of Engineering (GA8~GA10)



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Washington Accord Graduate Attributes

	WA Graduate (Professional)	SA Graduate (Technologist)	DA Graduate (Technician)
1. **Engineering Knowledge**			
2. **Problem Analysis**	Complex	Broadly defined	Well defined
3. **Design/ development of solutions**	Complex	Broadly defined	Well defined
4. **Investigation**	Complex	Broadly defined	Well defined
5. **Modern Tool Usage**	Complex	Broadly defined	Well defined
6. **The Engineer and Society**			
7. **Environment and Sustainability**			
8. **Ethics**			
9. **Individual and Team work**			
10. **Communication**	Complex	Broadly defined	Well defined
11. **Project Management and Finance**			
12. **Life long learning**			

INTERNATIONAL ENGINEERING ALLIANCE

(http://www.ieagreements.com/GradProfiles.cfm)

Washington Accord Complex Engineering Problem

In the context of both Graduate Attributes and Professional Competencies:			
Attribute	***Complex Engineering Problems* have characteristic WP1 and some or all of WP2 to WP7*:***	***Broadly-defined Engineering Problems* have characteristic SP1 and some or all of SP2 to SP7*:***	***Well-defined Engineering Problems* have characteristic dP1 and some or all of DP2 to DP7*:***
Knowledge required	**WP1**: cannot be resolved without in-depth engineering knowledge at the level of one or more of WK3, WK4, WK5, WK6 or WK8 which allows a fundamentals-based, first principles analytical approach;	**SP1**: cannot be resolved without engineering knowledge at the level of one or more of SK 4, SK5, and SK6 supported by SK3 with a strong emphasis on the application of developed technology;	**DP1**: can be resolved using limited theoretical knowledge defined in DK3 and DK4 but normally requires extensive practical knowledge as reflected in DK5 and DK6; :
Range of conflicting requirements	**WP2**: Involve wide-ranging or conflicting technical, engineering and other issues	**SP2**: Involve a variety of factors which may impose conflicting constraints	**DP2**: Involve several issues, but with few of these exerting conflicting constraints
Depth of analysis required	**WP3**: Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models	**SP3**: Can be solved by application of well-proven analysis techniques	**DP3**: Can be solved in standardised ways
Familiarity of issues	**WP4**: Involve infrequently encountered issues	**SP4**: Belong to families of familiar problems which are solved in well-accepted ways	**DP4**: Are frequently encountered and thus familiar to most practitioners in the practice area
Extent of applicable codes	**WP5**: Are outside problems encompassed by standards and codes of practice for professional engineering	**SP5**: May be partially outside those encompassed by standards or codes of practice	**DP5**: Are encompassed by standards and/or documented codes of practice
Extent of stakeholder involvement and conflicting requirements	**WP6**: Involve diverse groups of stakeholders with widely varying needs	**SP6**: Involve several groups of stakeholders with differing and occasionally conflicting needs	**DP6**: Involve a limited range of stakeholders with differing needs
Interdependence	**WP 7**: Are high level problems including many component parts or sub-problems	**SP7**: Are parts of, or systems within complex engineering problems	**DP7**: Are discrete components of engineering systems
In addition, in the context of the Professional Competencies			
Consequences	**EP1**: Have significant consequences in a range of contexts	**TP1**:Have consequences which are important locally, but may extend more widely	**NP1**: Have consequences which are locally important and not far-reaching
Judgement	**EP2**: Require judgement in decision making	**TP2**: Require judgement in decision making	

Complex Problem Solving Skills : General Context

- “The Future of Jobs”, World Economic Forum

  → significant changes in business models and the relevant workforce

  → a big change in the knowledge and skills required of employees,

  → complex problem solving skills to be the most important

  → study of LinkedIn members (400 million people): at most 6% have the complex problem solving skills - a huge gap!

- “Complex problem solving” - “the capacity needed to solve new, poorly defined problems in complex situations”

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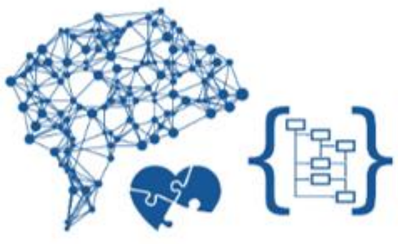
Top 10 skills

in 2020

1. Complex Problem Solving
2. Critical Thinking
3. Creativity
4. People Management
5. Coordinating with Others
6. Emotional Intelligence
7. Judgement and Decision Making
8. Service Orientation
9. Negotiation
10. Cognitive Flexibility



in 2015

1. Complex Problem Solving
2. Coordinating with Others
3. People Management
4. Critical Thinking
5. Negotiation
6. Quality Control
7. Service Orientation
8. Judgement and Decision Making
9. Active Listening
10. Creativity

Source : Future of Jobs Report. World Economic Forum

Complex Engineering Problem (Local Use by ABEEK)

- 4 domains (2 attributes per domain = 8 attributes)

- Breadth of knowledge
- Depth of knowledge
- Depth of analysis (Open-ended problem)
- Authenticity (Realistic problem)

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Complex Engineering Problem

- Breadth of Knowledge

1. Mathematics, basic sciences, computing and engineering fundamentals that support the discipline
2. **Comprehensive knowledge** applicable to the discipline

- Depth of Knowledge

1. A **theory-based understanding** of engineering fundamentals and discipline-specific knowledge
2. Analytical methodology based on relevant theories and principles

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Complex Engineering Problem

- Depth of Analysis (Open-ended problem)

1. Have no obvious solution which allows diverse perspectives

   and approaches to bear multiple possible solutions

2. Involve first principles based analytical thinking and abstraction in model formulation

- Authenticity (Realistic problem)

1. Involve wide-ranging or conflicting technical and engineering issues

2. Involve diverse realistic constraints

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Engineering Curriculum (Accreditation Criteria)

- Math, Basic Sciences, Computing (MSC)
- 1 Year of math, basic sciences (laboratory) and computing

- Engineering Subject
- Engineering science, design, laboratory/practice components
- Engineering design sequence: Introductory → Intermediate → **Capstone Design**
- Complex engineering problem in Capstone Design!

- Liberal Arts (Complementary Studies)
- 1 Year of liberal arts and complementary subjects

Mechanical Engineering Curriculum (at my Dept.)

<table>
<tr><th></th><th colspan="4">Standard</th><th>Recent Additions</th></tr>
<tr><td>Senior</td><td colspan="3" rowspan="2">Engineering Electives</td><td>Capstone Design
→ complex engineering problem</td><td>Specialization in
Bio, nano/mems, robotics, mobile, IT, energy, product design, manufacturing</td></tr>
<tr><td>Junior</td><td rowspan="2">Engineering Fundamentals</td><td>Systems, broader context:
Engineering systems</td></tr>
<tr><td>Sophomore</td><td>Materials Science</td><td colspan="2">Basic Electronics</td><td rowspan="2">Hands-on visualization, design & prototyping

A sequence of 2-3 design project courses</td></tr>
<tr><td>Freshmen</td><td colspan="3">Mathematics, physics, chemistry</td><td>Computer Programming</td></tr>
</table>

Role of Capstone Design in Accreditation

- Role of Engineering Design in Assessment of Achievement of Graduate Attributes

- Design Sequence in Curriculum: Introductory Design → Intermediate Design → Capstone Design
- Capstone design output used as a major assessment tool

- Assessment of each Graduate Attribute involves:

- Performance Criteria and Performance Level(s)
- Assessment Tools (Exit Test, Course-embedded, Capstone Design Deliverables, etc.)
- For Each Assessment Tool: Rubrics and Assessment Data
- Just for Capstone Design: Alignment with Complex Engineering Problems → Performance Level

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How to design Capstone Experience: Student Profile

• Strengths

- Recall theories and solve complicated (not complex!) problems
- Familiar with ICT tools / math-based engineering software

• Weaknesses

- Dealing with plurality of answers or uncertainty → "belief in one best solution"
- Overly trusting of printed information, instructions (instructors, advisors)
- Problem solving as mathematical exercise → engineering intuition & judgment?
- No teamwork experience prior to university

→ Cognitive dissonance: students good at knowledge recall but skills & attitudes??

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How to Design Capstone Experience

- Objectives

- Bridge **the gap**: hone skills and attitude needed to solve open-ended problem
- Apply the knowledge and methodologies of mechanical engineering to solve a **major engineering problem**
- **Practice** engineering design & prototyping, team work and communication (written & oral)

- Constraints

- Large number of students
- Faculty expertise in a narrow specialty → **provide mechanical systems** coverage
- Imparting **skills, attitudes** (how do you measure?) in a classroom setting

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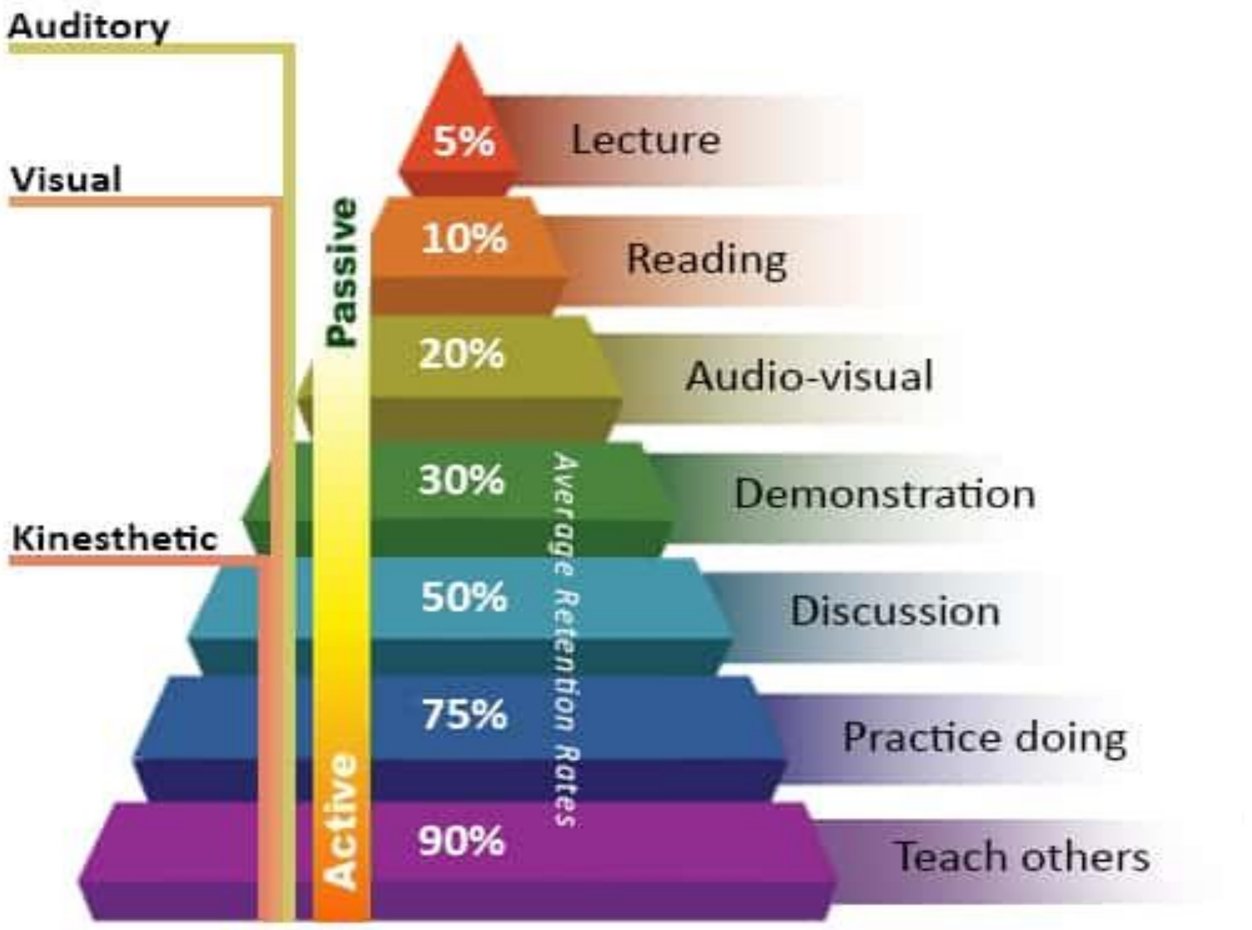
Learning Pyramid : Retention vs Resources Required



Adapted from the NTL Institute of Applied Behavioral Science Learning Pyramid

Features of Capstone Design Course

- Capstone Design Course Features

- 3 classes form a group (for each group, faculty drawn from 3 areas of dynamics/control, solids/production, thermal/fluid) → 3 faculty members provide coverage for one year
- Each class: 18 ~ 24 students (5~6 design teams)
- **Oral outputs:** Proposal, Mid-term and Final Presentation, Poster
- **Written outputs:** Proposal, Final Design Report, Thesis Paper
- Weekly team presentations, design progress reports
- Rubrics for different stages of design process
- Forms and templates (with published Rubrics)
- Grading: 75% team, 25% individual (instructor reluctance)
- Individual design activity report

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Stage I (2007-2013)

● Lectures (sizable knowledge component!)

- Weekly lectures on design process, needs analysis, document search, patents, teamwork, proposal writing, report and journal paper writing, presentation, cost analysis
- Additional lectures on design of experiments, design of scale models
- Special lectures by vendors of engineering software
- A written test on lecture materials

● Designing a product (design elements + constraints)

- Product design process: Needs analysis and ideation → concept design → detailed design (modeling and analysis, synthesis) → prototyping and testing
- Deal with realistic constraints, building a prototype

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Stage I (2007-2013)

- Focus

- Designing a product → solving an open-ended problem (in line with KEC2005)
- Experience all stages of designing a product (connection with graduate attributes not a major concern)
- Concept design, detailed design + teamwork and communication
- Prototype building (often rely on outside vendor for fabrication)

- Difficulties for Faculty

- No first-hand experience with undergraduate capstone design
- Gap between faculty specialty and design of mechanical products and systems
- How do you impart skills and attitude, not just knowledge

Alignment with WA *Complex Engineering Problem*

- **Wide-ranging or conflicting technical, engineering issues**
- **No obvious solution and require abstract thinking, originality in analysis**
- Research-based knowledge, a fundamentals-based, first principles analytical approach
- Involve infrequently encountered issues
- Outside of problems encompassed by standards and codes of practice
- Diverse groups of stakeholders with widely varying needs
- Significant consequences in a range of contexts
- **High level including many component parts or sub-problems**

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Stage II: Major Revision in 2014 (in line with KEC2015)

- **Cut down lectures to a minimum → emphasis on skills and attitude**

- Retain lectures on just two topics: design of experiments, design of scale models
- All other lecture materials as references/sample documents

- **Reset course objectives**

- Not limited to designing a product
- Emphasis on defining and solving a *complex engineering problem*
- Inter-disciplinary project as an option: (i) ME + industrial design
  (ii) ME + mobility (robots, autonomous vehicles)

- **Defining and Solving a Significant Engineering Problem**

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An Example

- Self-diagnostics for a Significant Problem

  → Is the level of difficulty and the knowledge required appropriate?

  → Is the scope and focus of the problem relevant to the practice of mechanical engineering?

  → Will the design activity involve mostly paper calculations/digital simulations such that physical validation of major outcome(s) would not be feasible?

  → Will the problem allow for creative approach and produce tangible outcome(s)?

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Final Team Outputs

- Year-end Department-Wide Event

- Poster presentation + Product Demo: ~40 design teams evaluated by the program faculty

- Graduation Thesis

- Design teams write graduation thesis using format of “KSME Journal of Technology & Education”, (Korean Society of Mechanical Engineers)
- Some are actually published in “KSME Journal of Technology & Education”

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Alignment with WA *Complex Engineering Problem*

- Wide-ranging or conflicting technical, engineering issues
- No obvious solution and require abstract thinking, originality in analysis
- Research-based knowledge, a fundamentals-based, first principles analytical approach
- Involve infrequently encountered issues
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- High level including many component parts or sub-problems

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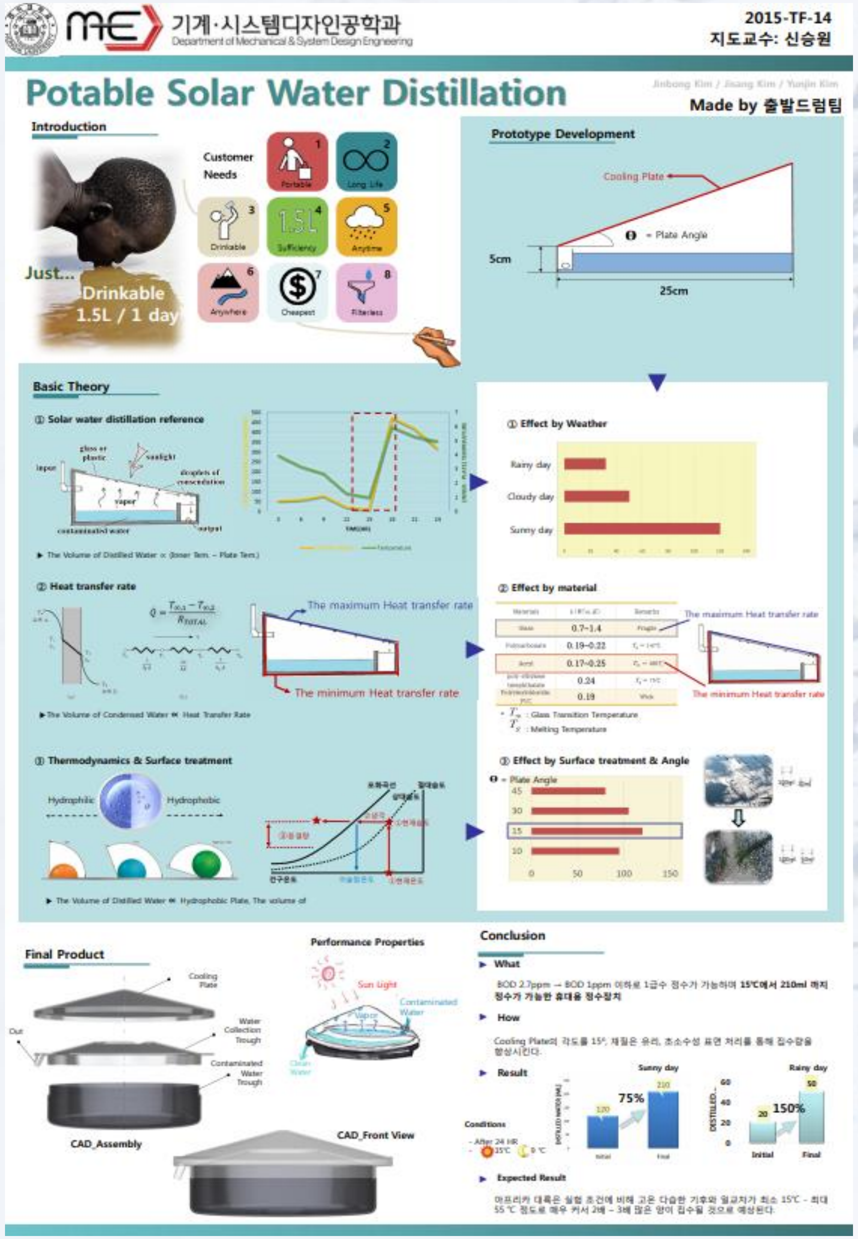
DESIGN A PRODUCT



BUILD & TEST

사단법인 대한기계학회 KSME

포스터 발표

지도교수 : 홍익대학교 기계·시스템디자인공학과 김관주 교수님

PROTOTYPE BUILDING & TESTING OF A Racing Car

김인환, 김승준, 백민철, 노현종
홍익대학교 기계·시스템디자인공학과

INTRODUCTION

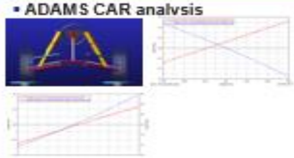
- 홍익대학교 기계시스템디자인 공학과 자작자동차 동아리 Light On
- 한국자동차공학회(KSAE)에서 주최하는 전국 대학생 자작자동차 대회 Formula 부문 참가
- 보고서 평가, 정적검사, 동적검사 3가지 평가 항목
- 동적평가는 가속, 스키드패드, 오토크로스, 내구레이스로 이루어짐.

DESIGN

LF-19 Formula 제원서		
1. 제원	앞 (전륜)	뒤 (후륜)
전장 / 전폭 / 전고 (mm)	2513 / 1425 / 1130	
축거 : 휠베이스 (mm)	1530	
윤거 : 트레드 (mm)	1180	1160
공차중량 (kgf) (드라이버 미포함)	전륜 : 90kgf / 총 중량 : 180kgf / 후륜 : 90kgf	
무게배분 비율 (%) (드라이버 포함)	50%	50%
무게중심 높이 / 최소회전반경	270 mm (드라이버 포함)	2.63m
2. 현가장치	앞 (전륜)	뒤 (후륜)
휠 제조사 / 규격 / 무게(kgf)	Keizer racing rim/10x6.25/1.67kg	Valken racing rim /10x6/1.6kg
타이어 제조사 / 규격	Hoosier Slick Tire (43101, 18x6.0-10 R25B)	Hoosier Slick Tire (43101, 18x6.0-10 R25B)
타이어 무게(kgf)/ 공기압(psi)	3.8kgf / 10psi	3.8kgf / 8psi
현가장치 타입	unequal length 더블 위시본	unequal length 더블 위시본
스프링 레이트 (Kgf/m)	2077 kgf/m	2077 kgf/m
모션 비 (스프링/휠센터 수직변위)	0.8	0.85
휠 레이트 (Kgf/m) (WR) = 스프링 레이트 * 모션 비^2	1329 kgf/m	1500 kgf/m
현가 진동수 (Hz) $= \frac{1}{2\pi}\sqrt{\frac{WR}{M}}$	2.37 Hz	2.43 Hz
M : 코너 스프링 상질량 (kg)	52 kg	55 kg
롤 센터 높이 (지면부터) (mm)	30mm	60mm
스태빌라이저(ARB) 장착 여부	장착	장착
댐퍼 제조사	DNM	DNM
댐퍼 감쇠계수 또는 그래프 (N/s/m)	Unknown	Unknown
3. 프레임		
프레임 Type (구조)	스페이스 프레임	
프레임 재료	탄소강 강관	
프레임 무게 (kg)	28 kg	
비틀림 강성 (Nm/deg)	Target : 2700Nm/deg	

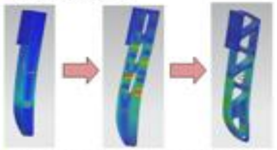
ENGINEERING ANALYSIS

- ADAMS CAR analysis



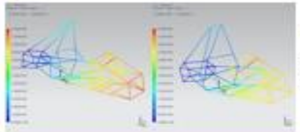
- 아담스 카를 이용한 동적 해석

- Pedal analysis



- 위상 최적화를 통한 페달 무게 30% 경량화

- NX-Nastran : frame analysis



- 2017 프레임 대비 비틀림 강성 40% 증가

Manufacturing

- 직접 제작하여 대회 참가

CONCLUSION

- 2018 KSAE 자작자동차 대회 Formula 부문 장려상
- 300cc 이하급 보고서평가 1위
- 모든 경기 부문 참가

RESEARCH TOPIC

홍익대학교 ME 기계·시스템디자인공학과
Department of Mechanical & System Design Engineering

2015-TF-08
지도교수: 박승호 / 김정수, 박성진

열적외선 카메라를 이용한 비염 환자의 체열 분석

THERMOGRAM ANALYSIS OF RHINITIS PATIENTS USING THERMAL INFRARED CAMERA

최범준 (A917175) 최현제 (A917180) 김재성 (B117033) 김정호(B117036)

Introduction

- 체열 진단법에 관한 임상 응용 논문 필요
- 질병 존재 부위만의 체열 분석은 사람마다 체열분포와 평균이 달라 정량적 분석의 어려움
- 분석이 어려웠던 비염의 새로운 분석법 필요

Experiment

측정 기준

- 온도 차(Y) = 이마온도-콧등온도
  - ✓ 이마온도를 기준으로 상대적인 콧등의 온도를 온도차로 표현

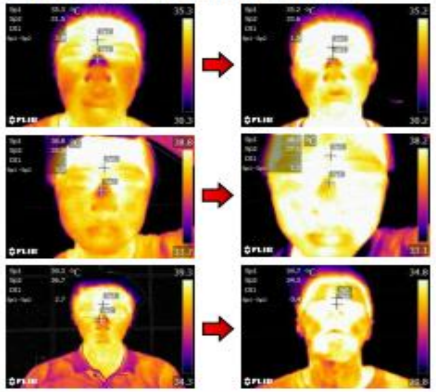
실험 방법

- 비염환자의 이비인후과 치료 과정 중 측정을 하고 체열 변화를 분석 (비염환자 3명 5회 측정)
- 신뢰성 확보 실험 추가 (비염환자,정상인 각 50명)
- 측정 부위 : 각 세 지점의 평균 온도로 정의

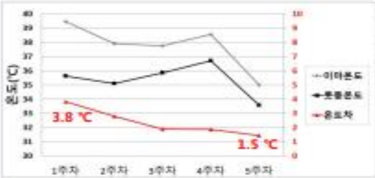
Results and Discussion

실험 결과

- 비염환자의 치료 전/후 열화상 카메라 사진



- ➢ FLIR Tools를 이용하여 온도구간의 크기를 5℃ 이마온도를 가장 높은 지점으로 설정 후 콧등 온도 비교
- 비염환자 치료 과정에서의 체열 변화 Graph



피실험자 2	
치료 전	치료 후
3.8	1.1

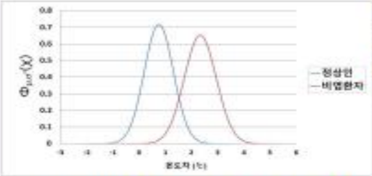
피실험자 3	
치료 전	치료 후
2.7	0.4

결과 분석

- 콧등의 온도만으로 분석이 불가능한 반면, 온도 차(Y)는 치료경과와 함께 꾸준히 감소함으로써 비염환자와 정상인을 나누는 기준이 됨을 의미

신뢰성 확보 실험 결과 및 분석

- 비염환자 정상인 각 50명의 온도 차 정규분포곡선



정상인	
평균	표준편차
0.76	0.79

비염환자	
평균	표준편차
2.34	0.86

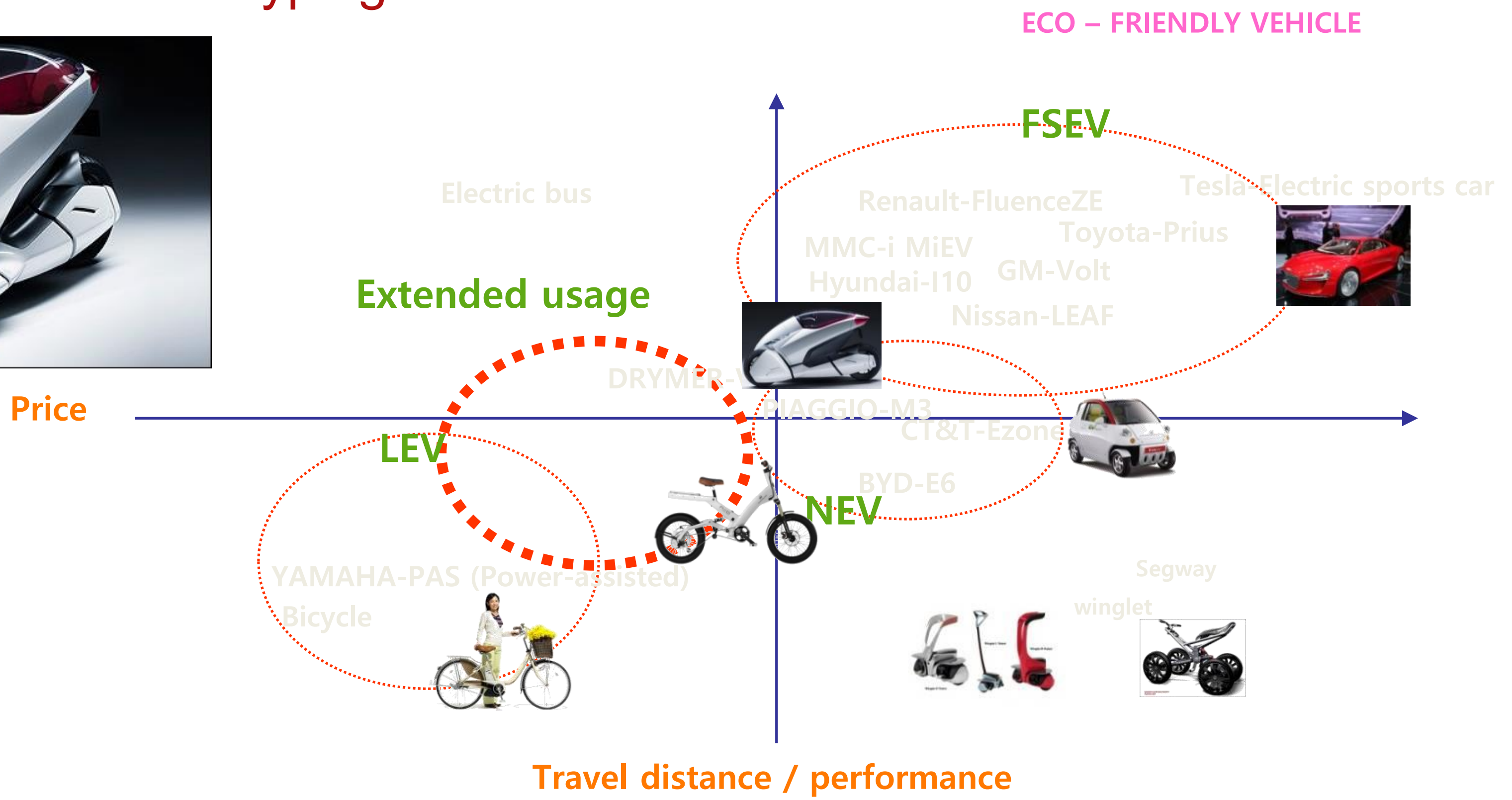
- ➢ 온도 차의 평균은 비염환자가 약 1.58℃ 더 높았다. 표준정규분포표를 이용하여 온도차 1.52 ℃ 이상에서 비염환자는 약 83% 정상인은 약 17% 확률 분포를 갖는다.

Conclusions

- 이마 온도를 대조 부위로 정하여 콧등 온도와 상대적인 차를 얻으면 보다 객관적인 분석결과를 얻음
- 본 연구에서 비염환자를 진단할 수 있는 정량적인 데이터로써의 활용
- 체열분석 데이터는 병을 진단하는 보조적 역할로만 사용

INDUSTRIAL DESIGN–ENGINEERING COLLABORATION

Hybrid tricycles : Design and Prototyping



1. Safety → 3wheel / Tilting technology
2. Efficiency → Electric motor and lithium-ion battery
3. Posture comfort for elderly → Recumbent / Semi-recumbent
4. Applications → Optional modules such as baby-carriage
5. Marketability → Affordable price and distinguishable style (2.5 ~ 5mil KRW)

KSME

Through capstone design, students

- Define a complex engineering problem
- Explore a multiplicity of approaches and techniques to solve the problem

  → basic analysis, modelling & formulation, computer simulation/building/experiment, testing & validation
- Apply the knowledge and skills in a novel context

  → "domain-transfer" of the knowledge and skills
- Realize viscerally that the "real-world" is inherently noisy and theories are limiting

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Thank you for your kind attention !