AC 2011-445: DEVELOPMENT OF A SUSTAINABLE DESIGN CHALLENGES WORKSHOP FOR SENIOR INDUSTRIAL ENGINEERING STUDENTS

(Ruth) Jill Urbanic, University of Windsor

(Ruth) Jill Urbanic received her B.A.Sc. in Mechanical Engineering at the University of Waterloo in Canada. After receiving her degree, she pursued opportunities to work in various advanced manufacturing environments. She has worked with several types of manufacturing, material handling, testing, gauging and assembly equipment for a variety of engine components and vehicle styles. She wished to expand her horizons by enhancing her practical background with more theoretical knowledge. To that end, she received her M.A. Sc. in Industrial Engineering and her Ph.D. in Mechanical Engineering at the University of Windsor. Dr. Urbanic is presently an Assistant Professor at the University of Windsor.

Her interests include integrating advanced technologies into manufacturing systems, in conjunction with balancing human characteristics and capabilities within the technical and business environments.

Susan S. Sawyer-Beaulieu, University of Windsor

Dr. Sawyer-Beaulieu has more than 30 years professional engineering experience, including 10 years in the mining and mineral processing industry, 7 years in the metals recycling industry, 8 years in consulting, and holds professional engineering licenses in Ontario and Quebec. She is currently working as a Post Doctoral Fellow at the University of Windsor funded under a MITACS Elevate Industrial Fellowship research grant, in partnership with the Ontario Automotive Recyclers Association. Her current research focuses are vehicle recycling, life cycle assessment, and materials recycling and recoverability.

Dr. Sawyer-Beaulieu has a B.A. in Biology and a B.Sc. in Mining Engineering (Mineral Processing specialization) from Queen's University, Kingston, Ontario, as well as an M.A.Sc. and Ph.D. in Environmental Engineering from the University of Windsor, Windsor, Ontario. Her diverse work experience includes (to highlight a few): conducting biological surveys for the mining industry; automation and optimization of industrial dewatering and waste water treatment plant operations; remediation of mine and mill waste disposal sites; the design and patent of a quick lime slaking system; designing zebra mussel control systems for a dozen water treatment plants in southwestern Ontario; performing environmental site assessments and investigations; establishing ISO 14000 environmental management systems for industrial facilities; and design of industrial air quality control systems.

Development of a Sustainable Design Challenges Workshop for Senior Industrial Engineering Students

1 Introduction

1.1 Introduction to capstone design project workshops

The classical senior capstone design course consists of establishing an environment where students are given the experience in solving a substantial problem while working in a team environment. The engineering design problems to which Canadian engineering students are exposed must be open-ended, and require the integration of curriculum elements¹. In the Industrial Engineering (IE) program at the University of Windsor, industrial sponsors from a variety of sectors (automotive, food, recycling, hospitals, and so forth) are engaged to provide real open ended projects to the industrial engineering students over a two term period. With realistic ill defined opened ended problems, the students are challenged to define the core functional requirements and relevant constraints prior to applying solution principles. The difficulty many students experience when trying to apply single-answer techniques to open-ended design problems can be significant and should not be underestimated². To facilitate these projects, the IE capstone course is structured as a set of workshops which emulate industrial training workshops to introduce or reinforce key project and design related concepts. Samples of the workshops are: “team building and communication”, “project management”, “tools and instrumentation”, “how to do a presentation”, and “understanding sustainable design challenges”. This paper focuses on the “sustainable design” challenges workshop. The goal of this workshop is intended to expose students to practical product life cycle issues, and the challenges related to designing products that consider sustainability concerns while ensuring that the solutions are economically viable and socially acceptable. The context of the sustainability challenges are reviewed in the automotive domain to provide scope. Practical systems, tooling, resource and business issues related to sustainably and productivity are discussed in context of human factors, materials, direct and indirect costs, and so forth throughout the workshop.

1.2 Introduction to sustainable engineering challenges in the automotive domain

An estimated 14 million vehicles are retired from the road annually in the U.S. and Canada, representing 20 million metric tonnes of mixed materials - metals, plastics, rubber, textiles, paper, wood, glass, ceramics, etc. (for an average “equivalent passenger vehicle” weight of 1455 kg)³. These end-of-life vehicles (ELVs) are typically processed first by dismantling (to recover parts and materials for reuse, remanufacturing, and recycling) followed by the shredding of the leftover dismantled ELV “hulks”, along with other metals-rich scrap (i.e. construction and demolition waste; end-of-life appliances (ELAs), for metals recovery and recycling. An estimated 14.4 million metric tonnes of shredded metals are recovered from these ELVs and recycled annually. The approximate 5.6 million metric tonnes of shredded, principally non-metallic materials generated annually from shredded ELV hulks is collectively referred to as shredder residue (SR) and primarily disposed of in landfills.

With the automotive industries efforts to meet legislated higher fuel efficiencies, the quantities of non-metallic materials that are generated from shredded ELVs are anticipated to increase as a result of the increased use of light-weighting materials in automobiles, such as, carbon fiber reinforced composites, glass fiber reinforced composites and plastics, including bio-based

polymers⁴. This will represent an increased challenge for auto recyclers to manage SR, particularly if ELV management in Canada and the U.S. should become regulated as it is in some countries, such as Europe and Japan. For example, under the European Union (EU) ELV Directive, EU Member States have been required to take measures to ensure that, by January 1, 2015, on average at least 85% of ELV materials by weight are reused and recycled and 95% go for reuse and recovery (including energy recovery)⁵. The challenge is “how to recover more ELV parts and materials for reuse, remanufacturing and recycling in a sustainable manner?”

In the manufacturing of any product – automobiles, appliances, robots, computers, etc. – design methods/principles are applied to ensure that products are designed, engineered and manufactured for quality, efficiency, productivity, safety and protection of the environment. But what is done at the end of a product’s life? We talk about reuse, remanufacturing and recycling, but how do we design for this? Designing a product to be sustainable throughout its entire life cycle (from raw materials production, to manufacturing, through use and then end-of-life) poses global, multi – disciplinary challenges with open ended solutions and unique optimization opportunities.

Designing vehicles, for example, for disassembly (also known as reverse assembly) versus dismantling represent very different challenges. A part or assemblage of parts recovered via dismantling may be significantly different than a part or parts configuration recovered according to vehicle disassembly specifications (original equipment manufacturer or OEM service/shop manuals), for a variety of reasons⁶. Dismantled part configurations can differ depending on how the parts are physically removed from a vehicle. For example, dismantlers will employ mechanized, semi-destructive dismantling techniques such as cutting, and may sacrifice parts of negligible value to access parts or assemblages that have much higher values for recovery and resale. The actual recovery of parts will vary depending on the dismantling difficulties encountered due to vehicle age, e.g., rust, and construction - many assemblages are simply not intended to be disassembled⁶. Parts recovered by dismantling will vary based on what parts are in demand and what parts are considered to have recovery value. How a dismantler recovers parts will be customized to optimize their removal and storage. For some dismantling operations, it may be more efficient to isolate and store groups of parts (not just single items as built by OEMs or their suppliers), which can then be dealt with or further dismantled into their constituent parts at a later time⁶. Presently engineering students are taught principles of design for assembly, logistics, supply chain, etc. To anticipate future needs, students must be introduced to practical sustainable engineering challenges, practices and solutions to extend their field of vision/perspective to include end-of-life issues.

2.0 Workshop

To understand practical sustainable design issues, a vehicle end-of-life (VEOL) workshop consisting of disassembling or dismantling selected vehicle sub-components (Table 1) was conducted. The outcomes related to the VEOL workshop focus on comprehending the issues associated with disassembly, i.e. reverse assembly (and reassembly), dismantling, reusing, remanufacturing, and recycling. Practical systems, tooling, resource and business issues are discussed in context of human factors, materials, direct and indirect costs, and so forth throughout the workshop.

Students were first given a brief introductory presentation to provide back ground information, as summarized in Section 1.2, and instructions about how the work shop would be carried out (i.e. structured tasks with strict time constraints; read through printed work instructions prior to starting the workshop tasks, etc.) Rubberized gloves and safety glasses were provided for students to use as needed. Three facilitators (two instructors and one technician) provided competent technical support and guidance to the students through-out the 2-hour workshop.

Over 30 students were organised into small groups (5 to 6 students per group) and each group assigned to a work station to dismantle or disassemble a part or sub assembly, donated by a dismantling facility, using a variety of hand tools (see Figure 1). One set of hand tools, consisting of sockets, wrenches, Allen keys and so forth, was made available per two groups. At each work station students were provided with printed work instructions, as illustrated in Table 4 (10 pgs in length) in the Appendix, that (1) describe the overall part type and, in the case of a parts assembly, recoverable sub parts that may be included on board and (2) show representative diagrams (from car service manuals) of the parts configuration for the subject part type (refer to Section 1 of Table 4). The work instructions also outline the tasks the students are to undertake at each stage of the workshop (refer to Section 2 of Table 4).

Students working on a parts assembly were asked to perform an assessment of the part assembly for parts or sub parts that are suitable for recovery for either (i) direct reuse, (ii) remanufacturing and reuse, or (iii) recycling. Students working on one of the individual parts (alternator or starter) were asked to assess the part's suitability for remanufacture or recycling. To assist the students with their assessment, the students were asked to answer a series of questions relevant to the part type or sub assembly they were working on (refer to Section 2 of Table 4). Forms were provided for recording the students' answers (refer to Sections 2 & 3 of Table 4). Dialogue between groups was encouraged to discuss similarities and differences in approaches, and challenges.

Students working on an individual part (starter or alternator) were required to disassemble the part according to a series of instructions using the provided hand tools, and where requested, conduct "quality assessment" tests on the part (e.g. "test stator for short circuits"). For each step or task, the students were asked to record on a provided worksheet (refer to Section 3 of Table 4) the disassembly steps, the tool(s) required for each step, the type and quantity of fasteners removed in each step (if applicable), the approximate time to complete each step and observations and/or comments about any difficulties experienced. This information facilitated a later formal assessment of the disassembly/dismantling tools and methods used.

Similarly, students working on a parts assembly were required to estimate "ease of recoverability" (from most easily recoverable part to least recoverable) for the parts/subparts assessed to be recoverable and then, using the supplied hand tools, disassemble several of the subparts from the parts assembly, in order of their estimated decreasing ease of recoverability. For each subpart recovered, the students were asked to record on a provided worksheet (refer Section 3 of Table 4) the disassembly steps, the tools required for each step, the type and quantity of fasteners removed in each step (if applicable), the approximate time to complete each step and observations and/or comments about any difficulties experienced.

Table 1: Vehicle End of Life Workshop Overview

			Time (min)
Introduction/ Background	4 groups working on Parts Assemblies	2 groups working on Individual Parts	20
Students do Parts Assessment	Assess Part Assembly for Reuse /Remanufacture/ Recycle: <ul style="list-style-type: none"> • Front Door Assembly • Steering Column Assembly • Radiator Assembly • Heater Assembly 	Assess Part for Remanufacture/ Recycle – Disassemble and reassemble part: <ul style="list-style-type: none"> • Starter • Alternator 	15-20
Student Discussion	- most recoverable part - least recoverable part	- challenges of work in progress	15
Students continue assessment work	Remove most recoverable part & one other of students choice (if time permits): <ul style="list-style-type: none"> • Estimate recovery time → cost • Note challenges, due to tool type; fastener type/ quantity/ condition; part/ fastener accessibility. 	Continue Part Disassembly & Reassembly Assessment: <ul style="list-style-type: none"> • Estimate disassembly/ reassembly time → cost • Note challenges, due to tool type; fastener type/ quantity/ condition; part/ fastener accessibility. 	15-20
Student Discussion	Part recoverability for Reuse? For Remanufacture? For Recycle? Why?	Part suitable for Remanufacture? For Recycle? Why?	15
Students finish up	Reassemble parts assemblies; Turn in tools	Turn in tools	15
Wrap-up Discussion	- Hand in worksheets - Check all tools are accounted for	- Hand in worksheets - Check all tools are accounted for	15

Figure 1 Examples of parts used in the VEOL Workshop

Using the collected data, and a supplied labour rate, the students were asked to estimate, review and discuss the costs and practicalities of recovering parts for reuse, remanufacturing and/or recycling. Upon completion of the disassembly tasks, the components were reassembled.

3.0 Workshop results

All of the students participating in this workshop stated that the workshop gave them a real appreciation for the relevant design challenges associated with sustainability issues. The students took this exercise seriously and worked well in their teams in discussing disassembly approaches and strategies, performing the physical tasks, and assessing related costs. Students noted that dirty/rusted/damaged parts, poor parts accessibility and lack of appropriate tools, made parts recovery difficult. However, it was observed that the students had difficulty translating IE tools to assess a non-standard problem. Overall, they had a lack of practical knowledge with respect to using hand tools, making good estimates and understanding manufacturing and assembly processes. In Table 2 there is a summary of the student assessments for the various components, and the instructors' assessment of the students work. The students also recognized their lack of exposure to practical knowledge. This is reflected in the student feedback survey (selected comments are presented in Table 3). Selected student comments related the usefulness of the workshop or desired changes are bolded.

Eight groups of students could easily be handled with the present format. As the students did not know how to use hand tools effectively, a complementary introductory tools and measurements workshop has subsequently been developed and implemented for the following academic year. This sustainable design challenges workshop has also formed a basis for an interactive poster to illustrate these disassembly and dismantling issues to the community at large.

4.0 Conclusions

In Platts⁷, two types of knowledge are identified: mode 1 and 2 knowledge. Mode 1 knowledge is defined as academic and discipline based, and is acquired from reading books, lectures and tutorials; whereas, mode 2 knowledge is practical, and trans-disciplinary. Action based activities are required to acquire this type of knowledge. Workshops have been designed to provide practical exposure to realistic design challenges that complements academic knowledge and virtual lab based activities. The goal is for all students in the course to receive hands-on relevant experiences within a safe learning environment. In this workshop students learned about practical issues associated with assembly, disassembly, dismantling with respect to time, tools, resources and considering practical business issues. They acquired an appreciation of the ergonomic and health and safety issues, and the optimization and efficiency challenges associated with dismantling /disassembly /remanufacturing / reassembly tasks, which is essential to fully understand the scope of sustainable design challenges.

Table 2 Summary of VEOL Workshop Results

Part	Student assessment related to following topics:				Instructor assessment:	
	Reuse	Remanufacturing	Recycling	Dismantling time	Related to student assessment	General workshop comments
Heater assembly	Steel bars, foam, plastic casing, HVAC blower, wiring, heater core, flap door	Foam, HVAC blower, wiring	Foam, HVAC blower motor needs cleaning	Understood key issues with respect to fastener locations Time analysis for unskilled people	Wear items are considered reusable - lack of knowledge Understood cleaning is required for reuse (blower motor) Need to test wiring to make a relevant decision Limited analysis performed as open ended decision making is required	<ul style="list-style-type: none"> Lack of practical knowledge with respect to using tools Difficulty translating IE tools to assess non-standard problem (task breakdown, time assessments ...)
Starter / Alternator		Functional – needs to be cleaned		Very thorough task breakdown and time assessments - estimates appear reasonable	Need to understand how to use a multi-meter	<ul style="list-style-type: none"> Lack of practical knowledge in order to make good estimates Difficulty in reading and understanding support material
Front door assembly	side mirror, door handle, power window motor, lock actuator	side mirror, door handle, power window motor, lock actuator	window glass	Ease of recovery - solid assessment: dismantled several parts	Understood value added / not value added components	<ul style="list-style-type: none"> Jumped ahead in disassembly tasks before assessing target areas based on potential value Lack of practical knowledge with respect to manufacturing processes
				Difficulty in removing interior door assembly - highest value 4:30 min.	Do not understand assembly techniques / spatial relationships	
Radiator Assembly	Fan, motors, radiator, air conditioner sensor, shroud, cap, rad. tank, filter condenser, wind flaps	Fan, motors, radiator, air conditioner sensor, shroud, cap, rad. tank, filter condenser, wind flaps	Rad. tank (plastic)	Very thorough task breakdown and time assessments - estimates appear reasonable	Confusion between remanufacture and recycle - broken cable would not be fixed	<ul style="list-style-type: none"> Acquired an appreciation of the ergonomic & health and safety issues with dismantling /disassembly /reassembly tasks
				Good assessment of ease of recovery issues, costs	Aggressive disassembly performed, reassembly also completed	
Steering column	steering wheel, combination switch, ignition switch, steering column jacket, lower bearing housing, upper steering coupler	Recognized missing components are needed to sell as complete subassembly	Add missing parts	Relatively simple component to disassemble - this group completed their tasks first	More challenging subassembly would reinforce concepts better	<ul style="list-style-type: none"> Acquired an appreciation of the optimization & efficiency challenges with dismantling / disassembly / reassembly tasks

Table 3 Selected student workshop survey comments

Overall quality*		Student Feedback		
Work -shop	Facilitators/ Instructors	What was the most useful or effective part of this workshop for you?	What changes would make this workshop more effective?	What else would you like to tell the facilitator(s)?
4	4	The hands on experience.	More time; circulating between stations so individuals experience different parts.	"It was awesome" "We should do it more often"
3	4	Learning to properly disassemble.	"It was very effective"	"Very good job, enjoyed the workshop"
4	4	Learning how to test for open/short circuits on the disassembled part	"The workshop was great!" Better described diagrams (pictures were hard to decipher)	"Great job; Had a blast!"
4	4	Gaining knowledge on the assembly and disassembly of automotive parts; as an engineer this important in the design process.	More time Use newer car model parts Components were missing parts - maybe have fully assembled parts.	"A great insight into the recyclability of automotive parts, such as cost, reusability and remanufacturing"
4	4	Cost effectiveness of assembly and disassembly Using tools	Some prerequisite knowledge	"You're good"
4	4	To learn about disassembling parts. It's more practical. The more practice we have, the more ideas we have about what's out there other than theory that we learn in class.	"Nothing. Everything's good"	"Thumbs up"
3	4	Being able to look at design for disassembly first hand Calculate cost per component to determine if component should be reused, recycled or scrapped	Give more of a background on testing circuits and how to evaluate circuits.	
4	4	Knowing the procedures for disassembling a car door Knowing the principles for car recycling	Showing a video that demonstrates the purpose of all the tools	"Good job. Keep up the good work"
4	4	To learn about the problems faced by the dismantlers	Give a brief introduction about the screws (i.e. fasteners) & tools before starting the workshop; would provide more knowledge to disassemble parts.	"Good workshop. Good to learn new things."
4	4	Problems and concerns about disassembly and how it is not standardized; Why are cars designed so differently? Car parts are designed only for assembly, not for disassembly.	Less reading; too many pages to go through.	

Notes: * Four-point scale used, where 1 = very poor, 2 = poor, 3 = good, and 4 = very good.

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Appendix

Table 4 Example of printed work instructions (10 pgs in length) for a parts assembly used for VEOL workshop

Section 1 Description of overall part type, and recoverable sub parts, and representative diagrams	
Part Type:	Front Door Assembly
Make, Model and Model Year:	1997 Pontiac Bonneville or 1990 Honda Civic 2-door
Hollander/Pinnacle Part Type Description	<p>120/DA+DB Door Assembly, Front Domestic coverage from 1965 to present. Foreign coverage from 1965 to present.</p> <p>DEFINITION: Forward doors. INCLUDES: Handles, locks; glass, glass frames; internal parts; welded hinge half, door shell. EXCLUDES: Bolted hinges; mirrors. Wiring harness variations are not considered. CONSIDER: Repair panel; glass; hinges; strikers; locks; handles; ground effects; mirror provisions; trim pads; door mounted belts; reinforcement bars; moldings, fenders, surrounding parts. NON-EXACT: Glass design (privacy, solar, theft, etc.) or shape, keyless entry pad; side impact bars (one way); ground effects molding price differences of \$200.00 or more, and requiring modification to the door which would make it impractical to interchange with a door of a different trim or option level; electric, manual windows; major changes to interior trim if trim can be switched; different design mirrors. Self-latching and self-closing option. DESCRIPTIVE NOTES: Chrome and painted handles, lock bezels and reveal moldings; anti-theft; glass tint; solar.</p> <p>MAY INCLUDE THE FOLLOWING SUBPARTS:</p> <p>125/DM+DN Door Window Regulator, Front Domestic coverage from 1965 to present. Foreign coverage from 1965 to present. © 2008 Audatex North America, Inc</p> <p>INCLUDES: Regulator or regulator and motor assembly. EXCLUDES: Motor when detachable. CONSIDER: Electric and manual. NON-EXACT: Different drive type (tape, cable, scissors) if interchange is affected. NOTE: All electric regulators are less motor unless otherwise indicated. NOTE: NOTE required when motor is included.</p>

Section 1 Description of overall part type, and recoverable sub parts, and representative diagrams

Example:

128/DK+DL Side View Mirror

Domestic coverage from 1980 to present.

Foreign coverage from 1968 to present.

INCLUDES: Mirror assembly, mirror head, motor, glass and cover.

EXCLUDES: Controls, inner attachment panel.

CONSIDER: Paintability of outer cover.

NON-EXACT: Heated and non-heated where wiring is the same; illuminated and non-illuminated.

NOTE: Right and left door mirrors in separate interchange numbers. Always reference R or L in index.

NOTE: Use the following sub-heads:

- Manual
- Cable
- Lever
- Electric

127 Front Door Molding

Example:

Section 1 Description of overall part type, and recoverable sub parts, and representative diagrams

129/DR Front Door Handle, Outside

Example:

129/DR Front Door Handle, Inside

Example:

181 Latches & Locks, Front Door Latch

Example:

181 Latches & Locks, Front Door Lock

Section 1 Description of overall part type, and recoverable sub parts, and representative diagrams

226 Window Crank, Front

Example:

277 Door Glass, Front

Domestic coverage from 1965 to present.

Foreign coverage from 1965 to present.

INCLUDES: Glass, moldings and trim; riveted parts; adhesive attached parts.

EXCLUDES: Regulator parts, gaskets, and scrapers.

NON-EXACT: Solar and security

NOTE: Solar glass used on R134a air conditioning system due to decrease in cooling capacity.

NOTE: Add OEM and NAGS (with tint and attachment codes) numbers for 1980-up applications.

617/DG+DJ Power Window Motor

Domestic coverage from 1965 to present.

Foreign coverage from 1967 to present.

INCLUDES: Motor.

EXCLUDES: Regulator, regulator arms (non-module types).

NON-EXACT: Wiring differences corrected with additional pigtails.

CONSIDER: Use in right and left doors or tailgate.

Section 1 Description of overall part type, and recoverable sub parts, and representative diagrams

Example:

643 Door Lock Actuator, Front Door
Example: (for Power Door Lock)

644 Front Door Speaker

VI Front Power Door Window Switch
Example:

699 Electrical Misc., Front Door Wiring Harness

Section 1 Description of overall part type, and recoverable sub parts, and representative diagrams

Examples of Front Door Parts Configurations:

(1) 1996-99 Chrysler Voyager (from 1996-99 Chrysler Voyager Service Manual):

Fig. 14 Front Door Glass Clips

Fig. 15 Front Door Glass

(VIEW U)

Fig. 18 Front Door Latch

Fig. 32 Front Door Manual Window Regulator

Fig. 33 Front Door Power Window Regulator

Student Names: _____

Section 2 Description of tasks and questions to be completed by students

Part A Assessment of Recoverable Parts for Reuse, Remanufacture or Recycling

Pretend you are a dismantler. Inspect the part, and with the assistance of the above information and your best judgment, assess the part assembly and/or its subparts for suitability for recovery for, either, (i) direct reuse, (ii) remanufacturing and reuse, or (iii) recycling. As you make your assessment answer the following questions. Record your answers on the worksheet provided.

(1) Is the parts assembly reusable as is (Yes or No)? Why or why not?

(2) If the parts assembly is not reusable, as is, is it remanufacturable (Yes or No)? Why or why not?

(3) If the parts assembly is not reusable or remanufacturable, as is, do you consider it to be recyclable (Yes or No)? Why or why not?

(4) Are there subparts on-board that you would consider recovering for reuse? If so, which parts and why? Hint: Consider part condition, material composition?

(5) Are there subparts on-board that may not be reusable, but you would recover for remanufacture? If so, which parts and why?

(6) Are there subparts on-board that may not be reusable or remanufacturable, but you would recover for recycling? If so, which parts and why?

(7) For the subparts identified in questions (4), (5) and (6), estimate ease of parts recoverability. For each subpart assign a value of ease of recoverability, e.g. 1, 2, 3, etc., from most easily recoverable part to least recoverable. Indicate factors taken into consideration, for example number of fasteners, condition and/or accessibility of part and fasteners, material composition of part (metal vs non-metal), etc.

Class discussion.

Part B Assessment of Part Recoverability by Disassembly

Assess the recoverability of the subparts identified in Part A. Disassemble the “most easily recoverable subpart” from the parts assembly, and, if time permits, one other subpart of your choice. For each subpart recovered, record (on the worksheet provided) the disassembly steps, the tools required for each step, type and quantity of fasteners removed in each step (if applicable), the approximate time to complete each step and observations/comments about any difficulties you experience. Based on the information collected, answer the following questions.

(1) For each part type, what is the total estimated dismantling time?

	Part Type	Estimated Total Dismantling Time
1		
2		

Section 2 Description of tasks and questions to be completed by students

(2) Based on a labour rate of \$30/hr, what is the estimated cost to recover each part?

	Part Type	Cost To Recover Each Part
1		
2		

(3) Based on your estimated part recovery cost, do you consider it economical to recover the part for reuse, for remanufacture, or for recycling? Why? Indicate your responses in the table below.

	Part Type	Recover for Reuse?		Recover for Remanufacture?		Recover for Recycling?		Explanation
		Yes	No	Yes	No	Yes	No	
1								
2								

Class discussion.

Part C Reassemble Parts

Wrap-up Class discussion

Section 3 Forms/worksheets for recording student answers

Part A Assessment of Recoverable Parts for Reuse, Remanufacture or Recycling

Name of Recoverable Part		Direct Reuse			Intended Part Disposition Remanufacture and Reuse			Recycling			Ease of Recovery (1= most easily recovered part, etc.)	
Part Assembly	Subpart	Yes	No	Reason(s)/Part Condition	Yes	No	Reason(s)	Yes	No	Reason(s)	Value	Factors Considered

Section 3 Forms/worksheets for recording student answers

Part B Assessment of Part Recoverability by Disassembly

Part Assembly	Subpart	Describe Disassembly Step (e.g. "Removal of plastic cover"; Removal of 4 screws, etc.)	Tool(s) Required	Fasteners		Time (min)	Observations/Comments about Difficulties
				Type	Quantity		
Estimated Total Dismantling Time							
Estimated Total Dismantling Time							