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Educating the Whole Engineer: Transforming an Introductory Engineering Survey Course

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1.0 Introduction and Background

Traditionally engineering education is the delivery of knowledge through the classroom experience. As time has progressed and the field has developed, engineering educational systems have moved towards delivering more and more information to our students in this "banking" model (depositing information without question or critique) at the expense of the development of the cognitive capacity for applying this knowledge to make judgments. Because engineers are continuously called upon to make judgments related to problems in complex systems, it is critical that we engage students in "self-authorship": the development of an internal voice that provides students with the capacity to define their beliefs, identities and social relationships, guided by their own visions and responsible for their own experiences and decisions[1]. Self-authorship includes a number of different enrichment processes, which most higher education institutions strive for their students to achieve[1-4]. The enrichment process for student development focuses on intellectual, identity and relationship development[5]. Self–authorship is seen as growth from internal to external ideas[1, 2]. Starting the process of developing self-authorship for students at the freshman level will be beneficial in laying the groundwork for them to continue the development throughout their undergraduate education[1].

To address this need, we modified an elective first year survey course, Engineering (Engr.) 110. This change reflects an initial effort to educate the "whole engineer" and to begin to transform the educational environment of our college by emphasizing engaged and reflective learning experiences for engineering students. Our vision was to advance the curriculum by intentionally providing students with greater opportunity to explore their identities, values and goals, and the broad educational opportunities provided to them through the unique learning environments at the University of Michigan.

To accomplish this vision, we: 1) revised the first year course schedule from 2 large lectures to a mixture of delivery mechanisms that include facilitated discussions of 20 students or less; 2) developed a curriculum in support of self-authorship via identity awareness; 3) engaged trained peer facilitators as discussion leaders; and 4) assessed learning outcomes associated with self-authorship for students enrolled in the course as compared to students outside the course.

In the following sections, we describe the results of a pilot study to assess learning outcomes associated with integrative learning, self-authorship and confidence in choosing a major.

2.0 Course Transformation

The overall goal of this course transformation is to increase students' level of self-authorship through exposure to a safe and welcoming learning environment in which to discuss topics such as their identities, values and goals, and the broad educational opportunities available at our the University of Michigan. Prior to this transformation, the course was delivered as a 2-day per week lecture held in an auditorium seating over 350 students. Despite the best efforts of faculty to engage students in this format, there was little to no meaningful interaction between student

and instructor. The redesign transformed the course into a lecture/discussion style, which was launched in Fall 2014. The lecture was still held in a 350-seat auditorium. However, the discussions section broke the students out into groups of 20 students or less. Upper level engineering students acting as peer facilitators led the discussion sections. In this study, the course transformation included structure and content of discussion sections, training and experience of peer facilitators, and assessment of the course.

Students who are unsure of choosing a major or want more information about the majors being offered at the University of Michigan are recruited into this first year elective course. The original course content, consisting of summaries of each of the engineering majors, was delivered lecture style and included 40-minute departmental presentations. This content was transformed to focus on the "grand challenges" of engineering that cross disciplinary boundaries and draw on expertise from more than one of the college's 14 majors. The departmental content lectures were reduced to 15-minute timeslots with 3 departments per lecture session sharing the relationship of the major to the "grand challenge" and broadening student understanding of the interdisciplinarity inherent in engineering problem solving.

To facilitate the development of self-authorship among first year students, we designed the discussion sessions as a developmental pathway introducing self-awareness, identity work and goal setting. The framework and details of the content were created and delivered by peer facilitators on a weekly basis. The peer facilitators were given time to add their own personal aspects to the content to imbue the session with personal credibility, create an respectful sharing atmosphere and engage students in open discussion. Table 1 provides a list of the discussion topics covered through the course of the semester. Appendix A1 provides the full session listing including the original course structure and the modified course structure with lecture topics included.

Table 1. List of content of discussion sections.

1. Professional Image
2. Common Reading Experience
3. StrengthsFinder[6]
4. Sustainability in Student Life
5. Globalization of the Engineering Field
6. Values, Priorities and Responsibilities
7. Metacognition & Academic Resources
8. Identity - Understanding Differences and Perspectives
9. Co-Curricular Opportunities
10. Professional Responsibility and Role in Society
11. Department Exploration Day
12. My Journey (Peer Facilitators Stories)
13. Goal Setting and Educational Planning

The role of the peer facilitators in this type of discussion format has been used effectively in the past at other institutions and in other contexts. For example, the Program for Intergroup Relations at our institution uses theory and experimental learning to facilitate student's learning on identity, social inequality, and intergroup relationships. They have established the value and importance of using peer facilitators in these types of small group discussion[7].

3.0 Research Questions

In the interest of understanding the influence that this course transformation might have on undergraduate engineering students, we investigated the following research questions:

1. Does inclusion of a discussion opportunity improve student development in (a) integrative learning and knowledge and (b) lay the groundwork for self-authorship beginnings?
2. At the end of the course, is the student more confident in declaring a major?

4.0 Methods

Survey Instrument

The survey instrument, (integrative learning survey) was developed, using a modified Self-Authorship Survey (SAS)[8] and a modified Integrative Knowledge Portfolio Survey self-assessment instrument[9], which resulted in a 33-item survey, see Appendix. Integrative learning is defined by the AAC&U as "an understanding and a disposition that a student builds across the curriculum and co-curriculum, from making simple connections among ideas and experiences to synthesizing and transferring learning to new, complex situations within and beyond the campus"[10, 11]. The Integrative Knowledge Portfolio Survey was designed "in order to create a pedagogy and technology to help students know and articulate what they have learned"[9, 11] especially valuing how they learn and implementing this in their career choices[11]. Pizzolato's SAS is the first tool of its kind to assess self-authorship quantitatively. The capacity to assess self-authorship quantitatively can help institutions create and implement new practices by having a tool that could be used for assessment. Prior to this, existing measures were used for cognitive gain[12], concept surveys to measure context and student's outcomes[13], and use of focus groups/interviews and reflections pieces[14]. New course structure and teaching strategies can be easily assessed using this tool and yearly modifications can be conducted. For specificity to our institution and course restructuring, we selected a subset of the factors to employ in our study based on the specific content that was delivered in the course. Table 2 provides the factors, concept names and number of items included in the instrument. Factors (1) through (5) were adapted from the Knowledge Portfolio Survey self-assessment, factor (6) was designed based on specific Engr. 110 course outcomes, and factors (7) and (8) are from the SAS.

The surveys were administered at the beginning and end of the Fall 2014 term to students enrolled in the course as well as a control group of first year students not enrolled in the course. The questions were given on a 5-point Likert-type scale from strongly disagree (0) to strongly agree (4) for each of the 33 statements.

Table 2: Integrative Learning Survey Factor Descriptions

Factors represent respondent capacity for:	**Concept Name**	**No. of Items**
1. Knowledge gained within and across specific contexts	Knowledge	3
2. Understanding and directing oneself as a learner	Self-Learner	3
3. Becoming a reflexive, accountable, and rationale learner	RAR Learner	3
4. Identifying and discerning one's own and others' ethics and perspectives	Ethics & Perspectives	3
5. Developing a professional digital identity	Digital	4
6. Course specific goals, which relate to career choices	Career	3
7. Self-authorship, Capacity of Autonomous Action: emotional and behavioral independence	Autonomous Action	3
8. Self-authorship, Problem Solving Orientation: need to reflect on their beliefs	Problem Solving	3

Participants

The integrative learning survey was administered to all 263 students enrolled in Engr. 110 (intervention group). As a control, we administered the survey in two other first year courses (Engr. 100 and Engr. 101). Engr. 100 is a required course where first year engineering students experience a hands-on approach to what it is like to be a practicing engineer. Students learn technical problem solving, creative engineering design process, technical writing and presentation skills, teamwork, professional responsibility, and decision-making skills. The goal of Engr. 101, also required, is to showcase and give students experience with computer languages to solve relevant engineering problems. To assure high levels of participation, we worked with faculty in required first year courses to administer the surveys in their classes. The enrollment for control and intervention group had 657 and 263 students, respectively. The breakdown of actual courses surveyed and enrollment numbers is provided in Table 3.

The control courses are required at the University of Michigan, which caused some overlap in students enrolled in both the control and intervention courses. To address this, we excluded

students who were enrolled in Engr. 110 from the control group. However, students enrolled in Engr. 110, were simultaneously enrolled in either Engr. 100 or Engr. 101.

Table 3. Study participants, showing intervention and control group sizes

Type	Course Name	Section #	No. of Students Enrolled
Control	Engr. 100	150	63
Control	Engr. 100	900	48
Control	Engr. 100	600	51
Control	Engr. 101	100	242
Control	Engr. 101	200	253
Intervention	Engr. 110	All (15 sections)	263

Analyses

To address our two research questions we used data from the modified integrative learning survey and compared student responses from the beginning to the end of the semester. For each of the 8 sub-factors we computed average level of agreement from the items included in each factor. Individual student gains were calculated (Gain = post – pre). Paired t-test was used when comparing pre and post responses within each group. Unpaired t-test was used when control to intervention was compared for significant difference. A reliability test was performed and Cronbach's alpha was calculated for the pre and post survey factors.

5.0 Results and Discussion

Demographics

Demographic data for the 920 students enrolled in the courses for this study are shown in Table 4. There are no noticeable differences in demographics for students enrolled in the control and intervention groups. The modified integrative learning instrument required completion at both the beginning and end of the term; response rates were 22% (N=144) and 80% (N=210) for the control and intervention groups, respectively. As stated earlier, the control response rate was low because we excluded those students who were simultaneously enrolled in Engr. 110.

Survey Reliability

We tested the factors in our survey because we used a modified version of the Self Authorship Survey and the Integrative Knowledge Portfolio Instrument. Table 5 shows each factor with the number of items associated for both the pre and post surveys. The Cronbach's alpha statistics indicate that all factors had a sufficient internal consistency given the low item number for each factor[15].

Table 4. Demographic data for all students enrolled

	Total (N= 920)	**Control (N=657)**	**Intervention (N=263)**
Gender			
Male	76% (701)	76% (497)	78% (204)
Female	24% (219)	24% (160)	22% (59)
Ethnicity			
White	59% (544)	56% (368)	67% (176)
Asian	24% (222)	26% (173)	19% (49)
Hispanic	6% (54)	6% (39)	6% (15)
Did not indicate	5% (44)	5% (35)	3% (9)
2 or More	4% (37)	4% (29)	3% (8)
Black/African-American	2% (18)	2% (12)	2% (6)
Native American	<1% (1)	0% (0)	0% (0)

Table 5. Cronbach's Alpha Values

Factor Concept Name	**No. of Items**	**Pre Survey**	**Post Survey**
1. Knowledge	3	0.62	0.61
2. Self-Learner	3	0.64	0.69
3. RAR Learner	3	0.60	0.58
4. Ethics & Perspectives	3	0.50	0.59
5. Digital	4	0.76	0.72
6. Career	3	0.66	0.58
7. Autonomous Action	2	0.62	0.67
8. Problem Solving	3	0.75	0.66

Integrative Learning and Knowledge (Factors 1 through 5)

To address research question 1(a), does inclusion of a discussion group increase a students' integrative knowledge and learning, we examined data (see Table 6 below) from sub-factors 1 through 5 (knowledge, self-learner, RAR learner, ethics & perspectives, and digital). To compare the starting levels of both the control and intervention groups, the pre average scores of the two groups were compared. It was our expectation that the scores would be similar for both groups across these five factors. However, the results reveal that sub-factor self learner (2) was significantly higher for the control group than the intervention ($p<0.001$). The self-learner sub-factor investigated how students' capacity for their own interests, values, and passions impact their learning and decision-making[9]. This initial difference may be due to the fact that students in the intervention course were often advised to take the course because they did not know what major they were interested in pursuing. This result suggests that students in the control (who knew what major to declare) may score themselves higher as a self-learner than the intervention

group. Overall, the control and the intervention group were at comparable levels for the other 4 sub-factors (knowledge, RAR learner, ethics & perspectives, and digital).

In exploring the pre to post comparison for the full control and intervention cohorts, only sub-factors knowledge (1) and digital (5) showed statistically significant differences out of the 4 sub-factors (knowledge, RAR learner, ethics & perspectives, and digital) that were not different in the pre surveys, as mentioned above.

Sub-Factor: Knowledge

The knowledge sub-factor (1) is a measure of a students' ability to "Demonstrate knowledge gained within and across specific contexts[9]." This shows how students gain knowledge through experience, declare it to others, and use it in different situations. For both the intervention and control groups, when comparing pre to post this sub-factor increased for students in aggregate at a moderately significant level (p-value<0.01). When comparing control to intervention the gain for sub-factor knowledge was not significantly different. This may be a result of overlap in content delivered in the intervention course and control courses. Encouragingly, both cohorts see an overall increased in this sub-factor. In the intervention course, this sub-factor was directly covered through discussion 6: Values, Priorities and Responsibilities. Because both cohorts of students were enrolled in the control course, while only the intervention cohort was additionally enrolled in the intervention course, it is impossible to tie any additional learning in this context to the intervention.

Sub-Factor: Digital

Sub-factor digital identity (5) refers to a students' ability to create and monitor an online professional repertoire. For both the intervention and control groups, when comparing pre to post, means of the digital sub-factor were significantly higher on the post (p-value<0.001). When comparing control to intervention the gain for this sub-factor was not significantly different. Similar to sub-factor knowledge, overlap in course content may be the cause for no significant gains when comparing to the control group. This sub-factor directly correlates to content provided in discussion session 1 for the intervention group: Professional Image. Again, while increases in this factor are encouraging, it is impossible to tie any additional learning in this context to the intervention.

Self-Authorship

To address research question 1(b), laying the groundwork for self-authorship development, we examined sub-factors autonomous action (7) and problem solving (8). Because self-authorship is a long-term characteristics developed over repeated significant experiences that must build over time[16, 17], for these sub-factors we expected to see very little to no change in this one-semester study. For both these sub-factors the control and intervention groups started at similar levels, with no significant differences in the pre surveys. In additional, the statistics reveal no significant differences for both sub-factors in a pre to post comparison for both the intervention and control groups. Comparing control to intervention we saw only moderately higher gains in sub-factor problem solving (8) for the control group (p-value=0.006). According to Pizzolato, problem solving relates to students' "commitment to and engagement in reflection on their beliefs[18]." As stated earlier, content overlap may have been the cause of why we see higher gains in the control

group. In a study conducted by Masi et.al, gains and losses over a period of two years were observed when surveying students at different intervals, pre freshman, post freshman, and post sophomore[19]. Because we administered the survey at only two closely spaced time points, it may be that the variance in response over time in these sub-factors is too great to indicate a reliable result in the aggregate.

Table 6. Differences in 8 Factors for the Modified Integrative Learning Survey

	Pre Score		Post Score		Gain	
Control (N=144)	Avg.	SE	Avg.	SE	Avg.	SE
Knowledge	3.13**	0.047	3.23**	0.043	0.10	0.047
Self-Learner	3.27*^	0.043	3.35*	0.046	0.081	0.046
RAR Learner	3.11	0.048	3.22	0.044	0.10	0.047
Ethics & Perspectives	3.07	0.051	3.15	0.046	0.076	0.050
Digital	2.34*	0.061	2.60*	0.057	0.26	0.054
Career	2.78**^	0.064	2.94**	0.060	0.15#	0.046
Autonomous Action	2.01	0.074	2.14	0.076	0.125	0.077
Problem Solving	2.95	0.057	2.96	0.057	0.28##	0.052
Intervention (N=210)	Pre Score		Post Score		Gain	
	Avg.	SE	Avg.	SE	Avg.	SE
Knowledge	3.00**	0.036	3.11**	0.033	0.11	0.049
Self-learner	3.07^	0.034	3.17	0.043	0.11	0.045
RAR Learner	3.11	0.037	3.07	0.040	-0.043	0.052
Ethics & Perspectives	3.05	0.038	3.17	0.037	0.12	0.051
Digital	2.25*	0.049	2.63*	0.045	0.38	0.065
Career	2.20*^	0.047	2.61*	0.046	0.41#	0.064
Autonomous Action	2.06	0.060	2.04	0.063	-0.019	0.081
Problem Solving	2.96	0.049	2.96	0.049	0.084##	0.059

Comparing pre vs. post:*p<0.001, **p<0.01
Comparing pre-control to pre-intervention: ^p<0.001
Comparing gains of control vs. intervention: #p<0.001, ##p<0.006

Confidence in Choosing a Major

To address research question 2, at the end of the course is the student more confident in choosing major, we analyzed data from sub-factor Career (6). This sub-factor is a course specific factor created to measure the student's level of confidence of choosing a major and how their values, interests, and strengths relate to different career paths. Actual questions are provided in Appendix A2. We expected to see differences in this sub-factor for control and intervention because students who enrolled the intervention course were typically encouraged to enroll because they express their uncertainty in what major they want to pursue during orientation. When comparing pre surveys for control to intervention, the control group exhibited a significantly higher pre survey average score than the intervention group (p-value<0.001), as anticipated. The career sub-factor was also significantly higher in the post survey for the intervention group (p-value<0.001) as compared to the control. The highest gain of 0.41 was shown for the intervention group and was significantly higher than the pre to post increase for the control (p-value<0.001). This shows that the restructure and inclusion of the discussion session increases the student's confidence in declaring major.

6.0 Conclusion

Preliminary results from our pilot study, modifying an elective first year survey course to include discussion intended to initiate development of self-authorship and integrative learning, show positive development of students in their confidence in choosing a major and linking this to their interests, values and strengths. This was a significant focus of the pilot course and shows that the curriculum is affecting students in a positive way as designed. Because we saw little difference in the sub-factors associated with self-authorship or integrative learning, but general gains in these values, we believe that these factors are already being addressed in the required first year courses and that the additional time that students in the intervention cohort spent on these factors was helpful, but not significantly influential. The control group currently has self-authorship and integrative learning developmental factors embedded into the first year curriculum. Future work will be proposed to study the self-authorship and integrative learning of both the control and intervention group, separately, so as to have a more definitive understanding of the impact of the intervention course.

Although not discussed above, a clear indicator of student engagement emerges in the instructor evaluations for the course. On a Likert scale of (1) strongly disagree to (5) strongly agree, the students ranked the peer facilitators as 4.8 ("The facilitator made me feel valued in the course"), and 5.0 ("The facilitator was an excellent teacher"). Students valued the discussion time, the facilitator, and established an element of belonging, feeling valued.

The developmental skills, which we chose to focus on in this study, such as self-authorship, and integrative learning, are skills that evolve over the total time spent at a university and in careers. Some students still lack in these skills upon graduation[1]. Future work to explore these factors should involve a longitudinal study that could provide insight to specific points in the curriculum or co-curriculum where students develop these skills. In addition, the Engr. 110 course assessment will shift focus to explore more specific learning outcomes associated more directly with the course and may seek a finer-grained assessment of skills associated with the longer-term

developmental constructs. Focus group data can be used to develop a stronger understanding of the learning taking place in this domain and to target assessment towards specific outcomes associated with the course.

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Appendix

A1. Course content and structure Fall 2013 and 2014

Style	Fall 2013	Style	Fall 2014
Lecture	Welcome to students; instructor outline class	Lecture	Welcome & Course Overview/Plan for Semester
Lecture	Future of Engineering	Discussion	Professional Image
Lecture	Engineering teamwork, creativity and entrepreneurship	Lecture	Future of Engineering - Grand Challenges
Lecture	Understanding your personal strengths	Discussion	Common Reading Experience
Lecture	Dept. of Materials Science and Engineering	Lecture	Consideration of Sustainability in Engineering
Lecture	Dept. of Naval Architecture and Marine Engineering	Discussion	StrengthsFinder[6]
Lecture	Panel of Employers from SWE/TBP Career Fair	Lecture	Engineering Responses to a Changing Climate
Lecture	Dept. of Nuclear Engineering and Radiological Sciences	Discussion	Sustainability in Student Life
Lecture	Dept. of Electrical Engineering	Lecture	Securing Cyberspace
Lecture	Creativity and Design	Discussion	Globalization of the Engineering Field
Lecture	Dept. of Atmospheric, Oceanic and Space Sciences	Lecture	Guest Speaker: Breaking out of Every Day
Lecture	Dept. of Aerospace Engineering	Discussion	Values, Priorities and Responsibilities

Lecture	Multidisciplinary Design Program	Lecture	Professional School: What is about?
Lecture	Dept. of Computer Science and Engineering	Discussion	Metacognition & Academic Resources
Lecture	Dept. of Industrial and Operations Engineering	Lecture	Engineering Devices
Lecture	Globalization and opportunities abroad - Int'l Programs Office	Discussion	Identity - Understanding Differences and Perspectives
Lecture	Dept. of Chemical Engineering	Lecture	Department Trio 1
Lecture	Dept. of Biomedical Engineering	Discussion	Co-Curricular Opportunities
Lecture	Graduate Education and Research	Lecture	Department Trio 2
Lecture	Dept. of Environmental Engineering	Discussion	Professional Responsibility and Role in Society
Lecture	Guest Speaker: My Journey	Lecture	Guest Speaker: My Journey
Lecture	Dept. of Mechanical Engineering	Discussion	Department Exploration Day
Lecture	Dept. of Civil and Environmental Engineering	Lecture	Department Trio 3
Lecture	Social and Environmental Responsibility; Ethics	Discussion	My Journey: Peer Facilitator Stories
Lecture	Minors, co-curricular opportunities	Lecture	Department Trio 4
Lecture	Student Presentations	Discussion	Goal Setting and Educational Planning
Lecture	Student Presentations	Lecture	Wrap Up

A2. Integrative Learning Survey Questions Mapped to 8 Factors

Factors	No. of Items	Survey Question
1: Demonstrate knowledge gained within and across specific contexts	1	I can provide evidence of how my personal values and beliefs have informed my decisions and actions.
	2	I can provide evidence of the knowledge and insights I've gained with regards to the strengths, limitations, and biases within my own perspective.
	3	I can clearly demonstrate the specific types of knowledge and skills I've gained from a wide range of learning and life experiences.
2: Understand and direct oneself as a learner	1	I can articulate specific examples of my personal values and beliefs.
	2	I can identify examples of how my personal values and beliefs influence my learning, decisions, and actions.
	3	I can clearly identify the passions, interests, and sources of curiosity

		that influence my learning, work and social life.
3: Become a reflexive, accountable and rationale learner	1	I ask questions and listen to others in order to understand if and how the needs, goals, perspectives, interests, etc. of all group members are being addressed in the group's decision making and activities.
	2	I often reflect on if and how my work (academic and otherwise) is meeting my own standards and expectations.
	3	I seek feedback on a regular basis in order to understand if and how my work (academic and otherwise) meets the needs, standards, and/or expectations of others.
4: Identify and discern my own and others' ethics and perspectives	1	I am aware that my background and social identities influence my perspective how I see the world and make sense of things.
	2	I can identify specific experiences where I have learned about the strengths, limitations, and/or biases inherent in my own perspective
	3	I ask myself, "Do my decisions contribute to the overall care, well being, or positive functioning of individuals, groups, organizations and communities that are a part of my life?"
5: Develop a professional digital identity	1	I understand the need to develop an on-line professional identity that is different from a typical social identity.
		I have shared relevant parts of my digital identity with specific audiences.
	2	I am taking steps to develop a professional on professional on-line identity that demonstrates my knowledge, skills, values, goals and contributions to others.
	3	I am continually updating and expanding my on my on-line professional identity in order to demonstrate my knowledge, skills, values, goals and contributions to others.
	4	I am continually updating and expanding my on line professional identity in order to demonstrate my knowledge, skills, values, goals and contributions to others.
6: Course Specific	1	I know how my interests, values and strengths related to choosing a major.
	2	I am ready to declare my major.
	3	I know how my interests, values and strengths relate to my career options.
7: Self-Authorship: Capacity for Autonomous Action	1	I tend to make decisions based on what people I admire think is best, even if it isn't always what I think is best.
	2	I have trouble making decisions that go against what people expect of me.
8: Self –Authorship: Problem Solving	1	When I think about my principals and morals, I know I've spent a lot of time figuring out why I believe these things.
	2	I think it's important to spend time figuring out what I believe about things.
	3	When I'm making decisions I spend time thinking about how my decision fits with my goals and principals.