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Modified K-12 Instructional Methods for Diverse Learners Applied to an Experiential Interdisciplinary Senior Design Course

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Abstract

There are multiple challenges associated with having diverse engineering teams (by discipline) learn and execute the design process such that each team member sufficiently gains the required capstone design skill sets. In this paper, we examine theories accepted among the K-12 and college educational literature for educating diverse teams and suggest solutions that have found common ground within both groups. Quality Function Deployment, Engineering Major Commonalities and Design Iteration techniques are explored within these contexts in conjunction with instructor experience. We argue these modified methods have a high probability of success based on their proven success at the K-12 level, when properly implemented.

Introduction

Interdisciplinary senior design capstone projects have been introduced in numerous engineering schools and colleges over the last few decades. As rapid technological advancement has proven that various engineering fields will increasingly merge in the 21st century and beyond, the increasing need for interdisciplinary experience is now well understood. A 2020 review of the topic by Van den Beemt et al [1] indicated that the central reported motivation behind interdisciplinarity in engineering education is that engineers are not yet being trained well to address complex real-world problems. which require interactions across disciplinary boundaries. Roy and Roy [2] argued that the evolution of hybrid fields combining two or more existing fields, and the bolstering of existing fields with an infusion of technological knowledge will be the future of engineering instructional pedagogy. Huutoniemmi et al [3] indicated that the working definition that studies on interdisciplinary engineering education seem to agree on is that interaction between fields of expertise requires some level of integration among those fields to count as interdisciplinary. These authors adopt this definition of interdisciplinary for this work.

The definition of interdisciplinary has not, however, been consistent. Some cases have involved a few engineering disciplines while others have involved multiple engineering disciplines or engineering disciplines combined with other disciplines such as marketing and business. The literature on interdisciplinary senior design engineering capstone courses is extensive. A few are presented here to illustrate the diversity of definitions, challenges, and solutions. Bannerot, Kastor and Ruchhoeft [4] described a senior design capstone course that consists of Electrical and Computer, Industrial and Mechanical Engineering majors. This course was developed at the University of Houston in 2003, the authors implemented changes in which many traditional topics were dropped for more “hands on” experiences. Redekopp et al [5] described a program piloted in 2008 which integrated an Electrical and Computer Engineering capstone course with a product development and branding marketing course. An “integrated assignment” model was adopted, in which students collaborated on assignments from their respective courses. A preliminary assessment showed that the students had an increased propensity for interdisciplinary and eventual transdisciplinary work after taking the course. Northrup [6] described a multi-disciplinary effort involving Computer, Electrical, and Mechanical Engineering students where teams of 6-8 students designed, built, tested, and raced an electric vehicle. Student feedback indicated communication was their largest challenge. The author recommended that a formal time be block scheduled for teams to meet more regularly and increase the level of communication. Additionally, faculty should develop a requirements document that describes what each discipline is responsible for and what designing and testing will be required that involves interdisciplinary interaction.

The literature on educating diverse groups at the K-12 level is equally extensive. There are several research-based methods generally accepted and adopted by the various departments of education in the US that have found success when properly implemented. As the average college student is now more distracted and has a shorter attention span than ever before [7, 8], it may be beneficial for the engineering instructional community to examine these secondary education techniques for optimizing instruction among diverse groups. Successes regarding dealing with diverse populations may carry over into an interdisciplinary senior design capstone setting, as this type of course epitomizes diversity of thought and specialty. Experimentation and adoption of relevant or modified techniques typically applied at the K-12 level for the Interdisciplinary Senior Design Capstone course may be in order. The relevant K-12 instruction concepts identified for this work are (1), Universal Design for Learning, (2), Zone of Proximal Development and (3), Culturally Responsive Pedagogy.

This work presents a case for novel approaches towards instructing an experiential interdisciplinary senior design experience based on STEM education literature at all levels, and insights based on instructor experience. We argue that solutions for the interdisciplinary senior design experience should be unique according to the type of majors enrolled. K-12 educational techniques for diverse populations are described, elements of which are modified and suggested as techniques that may satisfy instructional needs for the typical population within the interdisciplinary course. How does one get an Industrial and Systems engineering student excited about Material Selection and Design? or an Electrical Engineering student excited about time study as a component of a design solution? How consistent can the syllabus be with different combinations of majors each semester? These types of questions are explored in this work. The type of real-world examples used can greatly influence student engagement. Examples of commonalities among multiple fields that may serve to engage interdisciplinary all team members are also discussed.

Universal Design for Learning

The concept of Universal Design for Learning (UDL) argues that a one-size-fits-all curriculum does not promote optimal learning for a diverse student population. It therefore offers solutions that emphasize flexible approaches to teaching and learning that consider student diversity within the classroom context. Kieran and Anderson [9] indicate that as teachers plan, they need to be aware of their students' present levels in comparison with the lesson outcomes, skills, and standards. UDL has three principles that guide teachers' implementation [10]:

1. Provide multiple means of representation
2. Provide multiple means of action and expression
3. Provide multiple means of engagement

Research has shown that UDL is an effective teaching methodology for improving the learning process for all students [11] [12]. In this author's experience, there are many faculty that already apply these principles in a somewhat modified UDL form without any awareness of the formal term.

In the case of an interdisciplinary senior design experience, what might the UDL application look like? In this case, while there may be multiple forms of diversity in any course, we will focus on the diversity of majors as this is what differentiates the interdisciplinary capstone from typical capstone design courses. UDL applied in this case could be researching the major composition of the class, weeks before the start of the class, in order to start planning a framework specific to the class composition. The instructor must become familiar with the curriculum for all majors involved so that appropriate assignments and classroom discussions can be developed. This might involve assignments or even in-class work separated by major (at least initially) within the cognitive spaces where they are comfortable; all assignments being related to a common theme. Even the mechanisms in the assignment may vary, for example a Mechanical Engineering Technology (MET) major may get a more "hands on" assignment focused on the same theme compared to the assignment for the Industrial and Systems Engineering (ISYE) major. The ISYE major is comfortable in statistics and optimization, therefore this is where one might begin framing their assignment. An example of an in-class ideation exercise for the "Design of a smart autonomous lawnmower" is shown in Table 1. The tasks for each major relate to their major "culture" while also addressing an aspect of a common system.

Zone of Proximal Development

Lev Vygotsky's theory of learning and development defines the Zone of Proximal Development as the space between what a learner can do without assistance and what a learner can do in collaboration an instructor or with more capable peers [13]. Teacher awareness of the students' zones of proximal development has been shown to enhance student learning outcomes [14] [15].

Table 1: In class-exercise example using a modified UDL in the Interdisciplinary Course

Major	Exercise
ME	What type of suspension system would you use, why? How might you dampen vibrations mechanically?
ECE	What type of energy storage system might you use? Would you integrate solar? How might you dampen vibrations electronically?
RME	What actuators and sensors might you use? Sketch a possible configuration
CEE	How would the structural system be configured to optimize functionality? Sketch Load paths? Where should we have redundancy?
ISYE	What might the customer requirements be? Which related engineering specs would you seek to optimize, why?
MET	What materials might be important? What are the recommended manufacturing processes for these materials?

In the case of interdisciplinary design, the peers will typically be more capable within their own areas of specialty. Therefore, one objective could be that each major gains an equal level of knowledge in an area that belongs to every other major in their team.This is illustrated in Figure 2, the unions represent the new knowledge an ME major should gain when working with an ISYE, ECE and CEE major. Note, we then place every other major in the group at the center of the circle such that they all gain in other areas outside of their major equally.

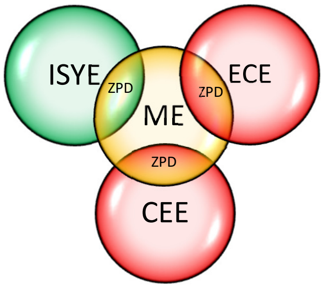

Figure 2 “Modified” Zones of Proximal Development for Interdisciplinary Senior Design Teams

One method to do this would be to have the ECE major present (5-10 mins) on an ME topic and rotate through the group so that all majors present on a topic outside of their major. This can be done throughout the semester to ensure one major presents on three other topics outside of their major (assuming a group of 4) by the end of the semester.

Culturally Responsive Pedagogy

Culturally Responsive Pedagogy (CRP) includes high expectations for every learner, cultural competence, sociopolitical awareness, and the classroom as a community [16]. CRP encourages teachers to select materials and modes of instruction that are accessible to their audience. Four overarching themes guide teachers to take a strength-based approach to diversity in the classroom. The term “strengths” refers to student’s abilities in various activities, ways of thinking and character traits, that they believe to be authentic, energizing, and performed well [17] [18]. Each theme is comprised of multiple facets for teachers' consideration when planning to teach diverse learners [19]. These themes are:

1. Awareness
2. Learning partnerships
3. Information processing
4. Community of learners and learning environment

All are applicable within an interdisciplinary senior design capstone setting. Awareness in our context refers to an understanding of the motivations, preferences, and ideas that will engage a particular student. This is an active process of inquiry that involves questioning and probing the student regarding their passions and interests. The other aspect of awareness would involve the recognition of academic barriers the student may face relative to other majors. Note there are other systemic societal barriers the instructor should be aware of, however, we are adopting CRP specifically for the diversity of majors in the interdisciplinary senior design capstone course and therefore will not include discussion of these other barriers in this work. CRP has been shown to yield successful student learning outcomes when properly implemented [20] [21].

Learning partnerships will organically develop as this course is project-based. Here it is important that each student within the partnership also develops awareness of the other students' motivation, background, interests, ideas, etc., this should be managed by the instructor. Information processing includes considerations related to the material's level of challenge and cultural relevance; modes of instruction, student engagement, authentic connections between school and community environments; and mastery-oriented feedback [9]. This is already included in the definition of teaching excellence at the university level for all faculty members.

The learning community is the classroom, it should be a safe space for learning, respectful collaboration, questions, mistakes, and conflicts [22]. There are sometimes negative stereotypes about the different majors ex. "Mechanical Engineering majors cannot program" or "Engineering Technology majors are not mathematically astute". These should be discussed and discarded.

Engineering Major Commonalities

As with any team, functionality is optimized when each member understands the capabilities and skill sets of every other member, assuming normal team dynamics. It is equally important that each major understands what the other engineering fields generally involve and the commonalities between these fields.

A well-known example that might be worth discussing would be the modeling of RLC circuits and spring mass damper systems using 2nd order differential equations with constant coefficients. Unfortunately, ISYE and Engineering Technology students do not take differential equations. However, these relationships can be expressed in terms of the first derivative only, which is well aligned with a Calculus I and II experience. Another expertise engagement activity may be to have the ECE/Robotics students define current, charge, inductance, resistance, capacitance, and Kirchoff's Voltage Law for the class, while the ME/AE/CE students define damping coefficient, spring stiffness, velocity, and displacement for the class. This may then be followed by a discussion on some commonalities among fields, examples are shown in Table 2 (not an extensive list).

Table 2. Concepts that demonstrate commonalities among majors

Electrical/Computer/Robotics Engineering	Mechanical/Aerospace/Civil Engineering
Voltage across a Resistor R $V = RI$	Force developed by a dampening system $F = cv$
Voltage across an inductor, L $V = L\frac{dI}{dt}$	Force acting on an object of mass m $F = m\frac{dv}{dt}$
Voltage across a capacitor with capacitance C, charge Q, current I $V = \frac{Q}{C} = \frac{1}{C}\int I\,dt$	Spring Restoring Force $F = kx = k\int v\,dt$
Power The electric power in watts produced by an electric current passing through an electric potential (voltage) difference of V is: $P = \frac{dW}{dt} = IV$	Power If a work interaction involves a macroscopically observable force, the rate of energy transfer by work is equal to the (dot) product (dot) of the force (vector) and the velocity (vector) at the point of application of the force: $P = \frac{dW}{dt} = \boldsymbol{F} \cdot \boldsymbol{v}$
Energy stored between the plates of a parallel-plate capacitor of capacitance C, voltage across plates V $\frac{1}{2}CV^2$	Energy stored in a linear spring of stiffness k undergoing extension x $\frac{1}{2}kx^2$
Kirchoff's current law $\sum i_{in} = \sum i_{out}$	Steady state mass balance for a control volume $\sum \dot{m}_{in} = \sum \dot{m}_{out}$
Electromagnetism For a wire carrying an electrical current I, then the magnetic field strength $\boldsymbol{dB}$ induced at point P by a segment of the wire $\boldsymbol{dl}$ with the current moving in the direction of $\boldsymbol{dl}$ $\boldsymbol{dB} = \frac{\mu I}{4\pi}\frac{\boldsymbol{dl} \times \boldsymbol{r}}{\lvert\boldsymbol{r}\rvert^3}$	Aerodynamics The elemental velocity induced at point P by the directed segment of the vortex filament $\boldsymbol{dl}$ with Vortex strength Γ is given by $\boldsymbol{dV} = \frac{\Gamma}{4\pi}\frac{\boldsymbol{dl} \times \boldsymbol{r}}{\lvert\boldsymbol{r}\rvert^3}$

Quality Function Deployment (QFD) for Interdisciplinary Teams

QFD is a typical design tool taught in most engineering senior design courses. Quality Function Deployment provides a structured approach to define and understand the design problem. It first involves identifying who the customers are and deciding what is important to which customer. The design group will then develop engineering specifications, i.e. engineering properties that measure how well each customer requirement is satisfied. QFD continues with developing target values for the specifications through market research, customer surveys, focus groups, etc., identifying the relationships between the specifications, and determining the relative importance of each specification.

For example, a customer may want an automobile with low noise and vibration. There are a wide range of measurable ways to adjust noise and vibration. The various majors will have ideas unique to their majors. These ideas, however, will typically assume a particular system is being used to solve the design sub function based on this specific customer requirement. Therefore, the example should come from a scope and level that all majors can understand yet does not assume a specific system. One could return to Hooke's Law, which ALL majors were exposed to in their Physics course, shown in Eqn. (1),

$$F = -kx \qquad (1)$$

where F is the Applied Force (N, lbf), x is the spring displacement (m, in) and k is the spring stiffness (N/m, lbf/in). We could then postulate some general k, associated with some general system (not necessarily a shock absorber) as a measure of the reduction of noise and vibration may be plausible here.

Design Iteration

To demonstrate the iterative nature of design while engaging specific majors, one can discuss an updated HOQ that occurs after the final conceptual design has been generated. For example, the stiffness of the automobile axle directly impacts noise and vibration. This can be measured by knowing the stiffness value given by EI/L^3 , where E represents the Youngs Modulus, I represents the moment of inertia of the axle cross section about its neutral axis and L, the length of the axle, assuming linear elasticity. The stiffness is therefore one specification that measures the low noise and vibration customer requirement. This example works well for mechanical, aerospace, or civil engineering students on the team, but what about electrical, computer, robotics, industrial,Iand systems engineering majors? In this case, we must consider what systems these fields might consider for the reduction of noise and vibration. Electrical, Computer, and Robotics engineering students may want to talk about the possibility of an Active Noise Control (ANC) system as shown in Figure 3. These systems will generally consist of vibration sensors, microphones, and speakers placed strategically to minimize the noise and vibration felt by the occupants [23, 24]. The related sensor and microphone specifications then become the "engineering specifications" that will measure the vehicle's ability to reduce noise.

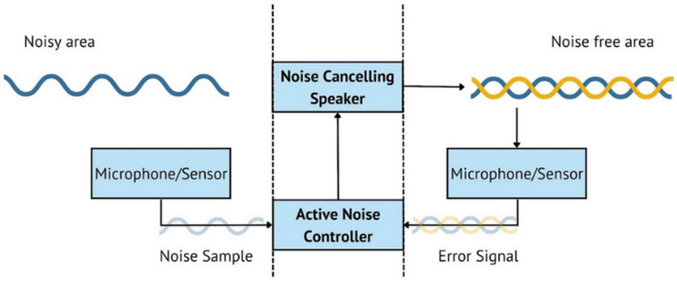

Figure 3 ANC block diagram (image from wewolmer.com)

What of the ISYE major regarding engineering specifications? The ISYE major is however typically not equipped with the tools for developing engineering specifications beyond what's taught in Calculus-based Physics. Therefore, all engineering specifications explored by that team must start with basic Physics.

The ISYE major has already been exposed to quality assurance in their previous courses. They have discussed in-depth topics such as reliability, performance, features, serviceability, quality, etc. ISYE seniors are also more well-versed in optimization and statistical modeling than their peers in other majors. Therefore, they could examine the design of the noise and vibration reduction systems offered by the other majors in their group for reliability, optimization, or quality. They would have to learn the new engineering properties used to describe these designs, This, however, is a key advantage in working in an interdisciplinary field, growth in knowledge for other major concepts and vocabulary.

Conclusion

Research-based systems designed for teaching diverse groups at the K-12 level have been reinterpreted for applicability to an EISD course. Techniques for introducing QFD, Design iteration, and promoting awareness of commonalities and differences among the various majors have also been posited. These techniques are a response to the rise of interdisciplinary design courses coupled with a more distracted generation with a shorter attention span. As the methods have been proven successful at the K-12 level, with proper implementation, there is a high probability of success of the modified techniques presented. The re-interpretations are necessarily diluted but have shown promise anecdotally through the author's experience. We recommend further study using both qualitative and quantitative assessments to validate initial observations of the implementation of these techniques.

References

[1] A. Van den Beemt, M. MacLeod, J. Van der Veen, A. Van de Ven, S. van Baalen, R. Klaassen and M. Boon, "Interdisciplinary engineering education: A review of vision, teaching, and support," *Journal of Engineering Education,* vol. 109, no. 3, pp. 508-555, 2020.

[2] M. Roy and A. Roy, " The Rise of Interdisciplinarity in Engineering Education in the Era of Industry 4.0: Implications for Management Practice," *IEEE Engineering Management Review ,* vol. 49, no. 3, pp. 56-70, 2021 doi: 10.1109/EMR.2.

[3] K. Huutoniemi, J. Thompson Klein, H. Bruun and J. Hukkinen, "Analyzing interdisciplinarity: Typology and indicators," *Research Policy,* vol. 39, no. 1, pp. 79-88, 2010.

[4] R. Bannerot, R. Kastor and P. Ruchhoeft, "Interdisciplinary Capstone Design at the University of Houston," in *ASEE Gulf-Southwest*, Arlingon, 2003.

[5] M. Redecopp, C. Raghavendra, A. Weber, G. Agussa and T. Wilbur, "A Fully Interdisciplinary Approach to Capstone Design Courses," in *American Society of Engineering Education Annual Conference and Exposition*, Austin, 2009.

[6] S. Northup, "A Multipdisciplinary Senior Design Project-Redsigned to Increase Interdisciplinary Interaction," in *ASEE Annual Comgress and Exposition*, Vancouver, 2011.

[7] K. M. Weber and H. Keim, "Meeting the Needs of Generation Z College Students through Out-of-Class Interactions," *About Campus,* vol. 26, no. 2, pp. 10-16, 2021 doi.org/10.1177/1086482220971272.

[8] A. Spence, k. Beasley, H. Gravenkemper, A. Hoefler, A. Ngo, D. Ortiz and J. Campisi, "Social media use while listening to new material negatively affects short-term memory in college students," *Physiology & Behavior,* vol. 227, 2020 doi.org/10.1016/j.physbeh.2020.113172.

[9] L. Kieran and C. Anderson, "Connecting Universal Design for Learning With Culturally Responsive Teaching," *Education and Urban Society,* vol. 51, no. 9, pp. 1202-1216, 2019, doi.org/10.1177/0013124518785012.

[10] R. D. H and M. A, Teaching every student in the digital age: Universal design for learning, Alexandria, VA: Association for Supervision and Curriculum Development, 2002.

[11] M. J. Capp, "The effectiveness of universal design for learning: a meta-analysis of literature between 2013 and 2016," *International Journal of Inclusive Education,* vol. 21, no. 8, pp. 791-807, 2017 DOI: 10.1080/13603116.2017.1325074.

[12] S. Sari Dewi, H. Anwar Dalimunth and Faadhil, "The Effectiveness of Universal Design for Learning," *Journal of Social Science Studies,* vol. 6, no. 1, pp. 112-123, 2019.

[13] E. Billings and A. Walqui, "Zone of Proximal Development: An Affirmative Perspective in Teaching ELLs," West Ed, NYSE Office of Bilingual Education and World Languages, San Francisco, CA, 2023.

[14] V. K. Zaretsky, "One More Time on the Zone of Proximal Development," *Cultural-Historical Psychology,* vol. 17, no. 2, pp. 37-49, 2021.

[15] A. A. Margolis, "Zone of Proximal Development, Scaffolding and Teaching Practice," *Cultural-Historical Psychology,* vol. 16, no. 3, pp. 15-26, 2020.

[16] A. B. A, "From teacher education to practicing teacher: What does culturally relevant praxis look like?," *Urban Education,* vol. 55, no. 8-9, pp. 1115-1141, 2020, doi.org/10.1177/0042085916672288.

[17] R. Galloway, B. Reynolds and J. Williamsson, "Strengths-based teaching and learning approaches for children: Perceptions and practices," *Journal of Pedagogical Research,* vol. 6, no. 1, pp. 187-202, 2020.

[18] A. Linley, Average to A+: Realising Strengths in Yourself and Others, Coventry, United Kingdom: CAPP, 2008.

[19] H. Z., Culturally responsive teaching and the brain: Promoting authentic engagement and rigor among culturally and linguistically diverse students, Thousand Oaks, CA: Corwin, 2015.

[20] G. Ladson-Billings, "Three Decades of Culturally Relevant, Responsive, Sustaining Pedagogy: What Lies Ahead?," *The Educational Forum,* vol. 85, no. 4, pp. 351-354, 2021.

[21] M. Tanase, "Is good teaching culturally responsive?," *Journal of Pedagogical Research,* vol. 4, no. 3, pp. 187-202, 2020.

[22] S. C., Whistling Vivaldi: How stereotypes affect us and what we can do., New York, NY: W.W. Norton., 2010.

[23] H. Sano, T. Inoue, A. Takahashi, K. Terai and Y. Nakamura, "Active Control System for Low-frequency Road Noise Combined with an Audio System," *IEEE Transactions on Speech and Audio Processing,* vol. 9, no. 7, pp. 755-763, 2001, doi: 10.1109/89.952494.

[24] A. Gonzalez, r. M. Ferre, M. d. Diego, P. G and J. Garcia-Bonito, "Sound quality of low-frequency and car engine noises after active noise control," *Journal of Sound and Vibration,* vol. 265, no. 3, pp. 663-679, 2003 doi.org/10.1016/S0022-460X(02)01462-1.