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Industrial Field Trips: An Integrated Pedagogical Framework of Theory and Practice*

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The purpose of this paper is to propose a learning-centered, scholarly, and pragmatic pedagogical framework for facilitating field trips for engineering students in cooperation with industry. Salient features of the field trip pedagogical literature from K-12 and science education are aligned as research goals. They emphasize that field trips need to involve curriculum links, follow-up, clear purpose, and active learning. They also affirm that field trips have the ability to yield social and affective learning, holistic learning in a dynamic system, long-term memory, and learning anchors. These goals are mobilized here by implementing Dewey's experiential continuum with Deming's plan-do-check-act cycle and constructive alignment. This teaching-learning methodology is tested with a case study: a Manufacturing Processes Design class of 17 undergraduate, industrial engineering students in an accredited engineering program. The research results, which span a semester, are aligned to evidence the literature goals along with additional academia-industry collaboration benefits from a student learning perspective. These added benefits include student engagement, deep learning (including affective learning), joy in learning, and community synergy. Thus, learning value for students is yielded from the proposed, rigorous framework for industrial field trips in engineering education; the framework accomplishes scholarly alignment with pedagogical literature in parallel with empirical results that ensure successful application in a pragmatic manner.

Keywords: industrial field trips; experiential learning; community learning space; plan-do-check-act cycle; constructive alignment

1. Introduction

Social cognitive learning theory advocates "a rich environment in which students and faculty share meaningful experiences that go beyond the one-way information flow characteristic of typical lectures in traditional classrooms" [1, p. 4.3]. The importance of community in education extends beyond the traditional classroom into communities of practice [2] and across knowledge fragmentation and territoriality in both academic and professional settings [3]. Field trips into industry can provide this bridge and drive holistic learning in a dynamic system. In a manufacturing system, relationships can be drawn between people, machines, materials, processes, products, the environment, and more. This enables engineering students and teachers to experience a novel learning space that is unbounded, revealing the complex nature of engineering problems and industrial systems in a web of connection subject to limitation and uncertainty—fertile ground for deep learning.

Science teaching literature has advocated the value of field trips for more than 30 years, predominantly in the K-12 school years [4–9]. Through the reported field trip experiences, students develop social and affective learning outcomes such as positive views and enthusiasm towards science [5,10, 11]. This, combined with evidence that field trips affect long-term memory [12, 13], makes field trips especially useful as learning anchors for students to connect and develop further cognitive and performative learning outcomes.

To successfully connect affective, performative, and cognitive learning outcomes with field trips and subsequent learning experiences a pedagogical framework is needed that ensures meaningful development for students. Field trips need to be embedded in a longer learning process [14] with clear curriculum links [15] and involve preparation and follow-up, clear purpose, and active learning [7–9]. To further develop these insights into a systematic approach, specific pedagogical frameworks have been suggested, such as for museum field trips for K-12 students [6]. There is a narrow body of research that discusses ad hoc field trips in the context of engineering education and manufacturing [16–18] but there have been no pedagogical frameworks suggested nor alignment with existing pedagogical methodologies.

This research thus proposes a pedagogical framework that addresses the field trip best practices in existing literature, investigating whether the benefits of field trips in science can be reaped in engineering education, and exploring deeper connections to pedagogical methodologies as a rigorous, systematic approach for industrial field trips in engineering education. This research examines how field trips can be designed into a course based on pedagogical philosophy (Dewey's experiential continuum [19]),

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developed in iterative learning processes (Deming's plan-do-check-act cycle [20]), and aligned with learning outcomes, active learning methods, and assessment (constructive alignment [21]). The proposed pedagogical framework is applied in a Manufacturing Processes Design course of 17 third-year, undergraduate, industrial engineering students and analyzed for its learning value.

2. Teaching-learning methodology

In *Experience and Education*, Dewey proposes the value of an experiential continuum, in which experiences "live fruitfully and creatively in subsequent experiences" [19, p. 28]. In the context of field trips, the aim is for learning and memory from the field trip to live fruitfully in prior and subsequent learning experiences, including reflecting on theory and informing other field trip experiences for deeper learning. A successful continuum also extends past the learning experiences within a course into professional practice and life experiences.

To implement this philosophy into practice, Deming's plan-do-check-act (PDCA) cycle is used [20]. This PDCA cycle is also mapped onto the constructive alignment pedagogical framework. Constructive alignment marries constructivist learning theory and instructional design by aligning learning outcomes, learning experiences, and assessment [21]. This alignment is shown with a student perspective in Table 1.

Table 1 outlines one PDCA sequence relative to constructive alignment. As the sequence is reiterated, the cycle bears continuous learning loops that yield continuous improvement relative to the learner. These learning loops are interconnected and intertwined and form Dewey's experiential continuum. This is illustrated in Fig.1.

Dewey's pedagogical philosophy of the experiential continuum [19], developed in iterative learning loops in Deming's plan-do-check-act cycle [20], and aligned with constructive alignment [21] is the methodological framework proposed for facilitating learner-centred industrial field trips in this research.

3. Results and benefits of the Academia-Industry Collaboration

The research methodology is applied to a case study of a third-year, undergraduate Manufacturing Processes Design course. The course is part of a university industrial engineering program accredited by the CEAB (Canadian Engineering Accreditation

Table 1. Aligning the PDCA Cycle, Constructive Alignment, and Student Perspective

Deming's Cycle	Student Perspective	Constructive Alignment
Plan	• Study theory and generate questions to bring on the field trip • Be aware of learning outcomes and relate them to the theory and the field trip (establishing relevance between theory and field trips)	Learning outcomes
Do	• Experience the field trip, ask questions and listen to others' questions • Gather data and information	Learning experiences
Check	• Use the experience (e.g. data and information gathered, affective impacts, etc.) to reflect on the connections between theory and experience via classroom discussions that highlight multiple perspectives • Learn through formative assessments that actively compare, contrast, and evaluate the Plan and Do phases (e.g. theory and experience, questions and answers, etc.)	Assessment
Act	• Share and receive formative feedback (through peer, self, and teacher evaluation) • Revise and grow into the next iteration of the PDCA cycle—create a new Plan	Formative feedback

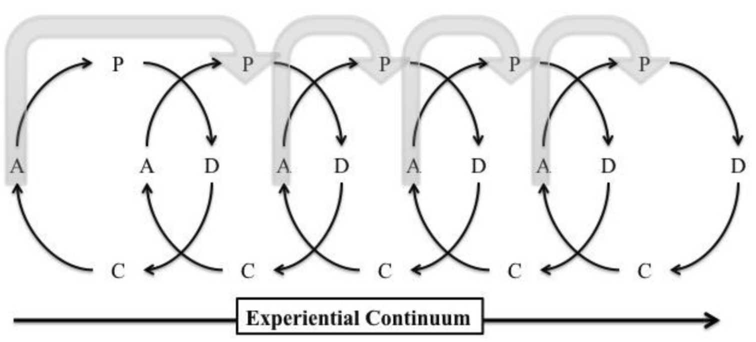

Fig. 1. Continuous Learning Loops: PDCA and Dewey's Experiential Continuum.

Table 2. Learning Outcome Assessment—Learning Complexity and Learning Domain

	Learning Domain			Bloom's Taxonomy				
Learning Outcome	**C**	**P**	**A**	**1**	**2**	**3**	**4**	**5**
1. Recognize and explain the following manufacturing processes: machining and material removal (e.g. drilling, milling, turning), forming and fabricating (e.g. casting, stamping), joining and assembly (e.g. welding), cutting (e.g. water jet, lasers), plastics (e.g. injection molding), composites (e.g. advanced composites lay-up), and additive manufacturing (e.g. 3D printing).	X			X				
2. Compare and contrast manufacturing processes with consideration to the relationships among material properties, processing methods, and process machinery (e.g. machine tools and other equipment) and their associated economics, environmental impacts, and safety considerations.	X	X				X		
3. Evaluate the suitability of a manufacturing process or processes in industrial applications, and to think critically about its/their value in industrial contexts.	X	X	X					X
4. Apply and grow the use of ethics and responsibility as it is applied to engineering work.		X	X		X			
5. Work effectively as part of a team.		X	X		X			
6. Utilize engineering tools (e.g. a process map, etc.) to analyze manufacturing processes.		X				X		
7. Dissect an engineered product by distinguishing the manufacturing processes used to manufacture its parts.	X	X						X
8. Create engineering reports and presentations that accurately and comprehensively discuss: problem and introduction, approach and methodology, observations, analysis, discussion, and conclusion.		X					X	

Board). The class consists of 17 students. The results are organized according to the methodology—Deming's plan, do, check, and act cycle.

3.1 Results of the plan phase

3.1.1 Defining and aligning learning outcomes

The first step in the Plan phase is to define the learning outcomes. In the case study, eight learning outcomes are defined for the course and then related to the field trips. The learning complexity of each learning outcome is analyzed relative to Bloom's Taxonomy—recollection and comprehension (1), application (2), analysis (3), synthesis and creation (4), and evaluation (5) [22]. The learning domain is also analyzed for each learning outcome: cognitive (concepts, ideas, theories), performative (skills, abilities), and affective (attitudes, dispositions, values). The results are summarized in Table 2.

Table 2 relates the case study learning outcomes to a range of learning complexities and learning domains. The proposed pedagogical framework for field trips is thus tested in a learning design with the potential for deep learning (versus surface learning). In addition, these learning outcomes are related to curriculum via the graduate attributes criteria of the CEAB (Canadian Engineering Accreditation Board) [23]. For the case study, this alignment (Table 3) was shared with students via the course syllabus.

Table 3 achieves the alignment from course learning outcomes to curricular graduate outcomes (in the case study, the CEAB Graduate Attributes Criteria). Other curriculum and accreditation graduate outcomes could be related for other contexts (e.g. institutional graduate attributes, CDIO (Conceive Design Implement Operate) learning outcomes, the Accreditation Board for Engineering and Technology (ABET) student outcomes, etc.). The course learning outcomes are further aligned to each field trip in the Do results (§3.2)—bridging learning outcome connection from field trip, to course, to curriculum.

3.1.2 Assessing if a field trip is an appropriate learning method for the class

Assessing the students' initial attitudes and predispositions towards field trips as a learning method is also an important step in the plan phase. For the case study, thirteen students voluntarily and anon-

Table 3. Aligning Course Learning Outcomes and Curriculum/Accreditation Graduate Outcomes

CEAB Graduate Attributes Criteria [23]	Course Learning Outcomes
A knowledge base for engineering	1, 2, 7, 8
Problem analysis	3, 7, 8
Investigation	1, 2, 3, 6, 8
Design	2, 3, 4
Use of engineering tools	3, 6
Individual and team work	5
Communication skills	8
Professionalism	2, 4, 5
Impact of engineering on society and the environment	2, 3, 4
Ethics and equity	2, 3, 4, 5
Economics and project management	2, 5
Life-long learning	

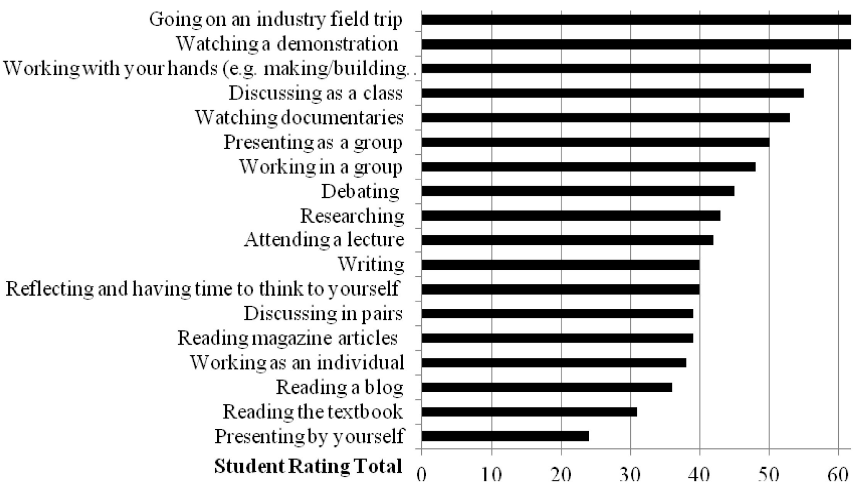

Fig. 2. Assessment—Students Ratings on Interest in Industrial Field Trips and Other Learning Methods.

ymously answered the question: please check off what methods of learning you find very interesting, fairly interesting, or not interesting. For simple comparison and analysis, very interesting is given a rating of five, fairly interesting a rating of three, and not interesting a rating of zero. These results are presented in Fig.2.

Figure 2 illustrates that among the thirteen students who participated in the survey, each one rated industrial tours as very interesting (a perfect score of $5 \times 13 = 65$). Thus, there was a strong predisposition for students in the case study to be genuinely interested in participating in industry field trips. The specific results will vary from class to class, and a pre-assessment that inquires into preferred learning methods helps to clarify student interest in field trips relative to a particular class. The pre-assessment for this case study also captured student expectations for the course and prior industry experience. The majority of the students stated that they had no prior industry experience, which may be a reason why industrial field trips were so appealing to the students and why the industry collaboration offered a unique and desired value for the students.

3.1.3 Preparing students for health and safety

Another significant aspect of the plan phase includes preparing students to be safe in the industrial environment. For the case study, this included educating students on safety boots and stipulating safety boots as a requirement to attend each industrial field trip. Students participated in WHMIS (Workplace Hazardous Materials Information System) training for health and safety. Even though a teacher and industrial guide always accompanied students during each field trip, each student was responsible for completing an online WHMIS training and providing a certificate of completion to the instructor before attending a field trip.

Guided field trips are a prime opportunity to emphasize industrial health and safety in what for many students may be their first exposure to an industrial environment (as the case study pre-assessment indicated). Practices such as this lend the opportunity for an industrial field trip to initiate a habit for industrial safety from the standpoint of awareness and concern. Instilling this knowledge and attitude in the minds of young engineers is a significant opportunity afforded by the field trip through its ability to connect cognitive and affective domains. In other words, through the field trip students come to *know* about industrial safety (cognitive domain) and more importantly students come to *care* about industrial safety (affective domain), relative to their industrial field trip experience and their own and their peers' health and safety.

3.1.4 Investigating students' predispositions to the industrial environment as a learning setting

In addition to health and safety preparations, it is also important to prepare students to be respectful of, open to, and aware of the industrial environment as a place of learning. For this reason, it's important to face predispositions to the industrial context (e.g. bias, stereotypes, etc.). For example, the industrial guides may not have a university education and have been educated differently than the students and the teacher (e.g. through apprenticeships, through the school of hard knocks, etc.). To become learning partners in the field trip requires the participants to believe that the knowledge and perspectives that the guides offer have significance. Ultimately, this means being able to not only respect differences (such as the differences in education) but, also, value differences.

A thoughtful discussion is an appropriate learning method for questioning and expressing perceptions of the industrial environment. Discussion "gives students a chance to explore ideas and discover new angles, pathways, problems and solutions" and "aids personal development when students have opportunities to refine and clarify their attitudes, beliefs, and values" [24, p. 11]. For the case study, a class discussion was facilitated that reflected on the documentary *The Tradesmen: Making an Art of Work* [25]. The documentary features tradespeople sharing their stories first-hand and the cultural biases that they've encountered and faced. It also addresses stereotypes on different kinds of education (e.g. on applied knowledge, apprenticeships, etc.). Discussion on the film, and the viewpoints and information shared in it, created the opportunity for the students and the teacher to, together, challenge their own and society's prejudices towards tradespeople (including their education and their work) while also reflecting on their own education and work. To further digest the discussion, film, and question beliefs, students were given an assessment that engaged critical thinking.

Discussions such as this enable doubts to surface, challenges to open, and respect for diversity to be championed. It enables the class to gain insight into, and appreciation for, people in diverse roles in the industrial environment. The field trip experiences further reinforce this discussion as people in various industry roles offer up their knowledge and experience and engage with students in the question and answer (Q&A) session, as in the case study. It is meaningful for students to learn this appreciation and humility in the context of the course—to be open to learning in the industrial context, to reinforce respect for diversity, and to value inclusivity. This self-awareness also positions the students and the teacher to further connect the field trip experience into their professional engineering practice, to approach the industrial environment with reverence and collective inquiry—an approach fundamental for effective teamwork.

3.1.5 Additional planning for the field trip experience

Suggestions for field trips can come from many different sources. These sources can include: students, fellow teachers, technicians in the university, industrial research collaborators, professional colleagues, newspaper articles, trade publications, co-op coordinators, even Google. The case study utilized many of these sources.

For the case study, each industrial field trip had an industrial guide who led students through the industrial setting (e.g. manufacturing facility), shared their knowledge, and facilitated the Q&A session. In the museum field trip literature, this role is called a docent [4]. In the case study, people from a variety of roles in the industrial setting were guides (e.g. a lead hand, tradesperson, cost estimator, purchase manager, quality manager, human resources manager, engineer, operations manager, etc.). The main guide, the point of contact for the teacher, was instrumental in discussing beforehand the direction for the field trip in alignment with the learning outcomes and with respect to students' prior learning (e.g. past field trips and theory)—a discussion that articulated the experiential continuum. From this, the industrial guide answered students' questions and shared information relative to the students' past experiences and learning outcomes. Because this evolved in the medium of discussion, students also had the opportunity to ask for clarification (further refining their own experiential continuum).

In the case study, students also prepared for the field trip by attending the class beforehand to learn the related manufacturing processes theory. The learning outcomes were related to the theory, and the use of agendas specified related learning outcomes to the class. Students reflected on this theory and each student created two questions to bring on the field trip.

3.2 Results of the do phase

In the Do phase, the students and the teacher experience the field trip with the industrial guide and have the opportunity and responsibility to ask questions, listen to other's questions, listen to information that's shared, and critically think about the answers to the questions. Questioning leads the learner out of the plan phase of theory into the do phase of field trip experience in alignment. In addition, the industrial environments offer themes that connect the learning outcomes to new concepts and ideas, and these bring new context and meaning to the learning outcomes. For the case study, the following field trips, which target learning outcomes 1–5, were conducted in the sequence outlined in Table 4. Table 4 also shows the themes offered by each field trip's industrial environment.

Table 4 relates the learning experiences and learning outcomes to a broad range of unique and valuable themes offered by the field trip's industrial setting. This emphasizes that the learning outcomes do not exist in isolation but in relation to the industrial context's interconnected web of people, machines, materials, processes, products, and broader environments (e.g. the economy, labour movements, ecosystems, etc.). This translates into

Table 4. Field Trip Learning Experiences, Aligned Learning Outcomes, and Industrial Environment Themes

Field Trip	Themes Offered by the Industrial Environment, in Addition to Targeting Learning Outcomes 1–5
1. Sand casting manufacturer of engine blocks	Highly automated casting; Material handling with very heavy parts; Automotive industry; Aluminum casting; Pattern-making and assembly; Post-processes such as heat treating and machining; Part accuracy; Unionized environment; Material science and engineering.
2. Injection molding manufacturer of automotive parts	Automotive industry tier 1 supplier; PPAP (Product Part Approval Process); PFMEA (Preventive Failure Modes and Effects Analysis); SPC (Statistical Process Control); Pneumatic automation; Material handling with lightweight parts and pneumatics; Inspection, fixtures, and gauges; GD&T (Geometric Dimensioning and Tolerancing); Packaging (e.g. reusable totes/crates designed by the customer); JIT (Just in time) shipping; Unionized environment; Perspectives from a cost estimator, program manager, human resources personnel with varied education (technology, business and management).
3. Large job shop and fabricator of die sets, winches, mining cars, etc.	Large machines (e.g. laser cutters, rotary surface grinders, flame cutting); Workforce training in-house; High cost inventory; Cranes and gantries for material handling; Lean manufacturing in a job shop and its challenges; Perspectives from engineers who work in several roles; Economic challenges in the tool and die industry; Private equity companies vs. public; Post-processes such as heat treatment and shot blasting; Robotic welding; Management of high-cost scrap—sales and recycling.
4. Medical manufacturer of tablets	Material flow and people flow; Design for non-contamination and use of air locks; Sterilizing processes; Control of dust; Batch processing; Specialized machines (e.g. ribbon blender, high shear mixer, small dies); Packaging production line; Poka-yoke; Diverse inventory and adaptive warehousing techniques; Documentation, its longevity and importance; Sampling and experimentation; Non-unionized environment; Medical industry; Energy efficiency in plant engineering; Worker safety.
5. Small shop machining custom parts	Detailed explanation on machine tools, tooling, and tool changers; CNC (Computer Numerical Control) vs. NC vs. manual; Complex CAM (Computer Aided Manufacturing) systems; Metalworking fluids and chip control; Roughing vs. finishing tool paths.
6. Additive manufacturing studio	Geometric freedom of additive manufacturing; Simple CAM systems; Prototyping; Post-processes such as support material removal and coatings; Manufacturing time comparison to traditional manufacturing such as machining.

a system view of interacting information, activities, and vantage points for learning. Pedagogically, this directly relates to Biggs' relational level of understanding in the SOLO (Structure of Observed Learning Outcomes) taxonomy.

The SOLO structure outlines stages of increasing structural complexity corresponding to how a student constructs understanding relative to, for example, the learning outcomes. The relational stage comes after pre-structural, uni-structural, and multi-structural and comes before extended abstract; it emphasizes students making meta-connections, understanding both the parts and the whole [26]. The field trip experience thus yields the opportunity for students to develop deep learning by connecting the learning outcomes to a broad, complex industry context.

The industrial guides and partners play an important role in bringing this context to life. In the case study, in a class discussion following a field trip, a student asked how the industrial company selected its suppliers. The class emailed the industrial guide the question. The Human Resources Manager worked with the company President to formulate a reply and gave the students a complex, multi-tiered answer dependent on the circumstance. The answer contextualized the solution for the many ways in which suppliers are selected, including the use of original equipment manufacturer (OEM) databases and approved suppliers, global databases of materials specifications and suppliers, request for quotation (RFQ) processes, using sensitivity analysis on the quotes, analyzing attributes such as geographic proximity, supplier responsiveness, creativity, flexibility, and track record. Furthermore, the President shared with the students how suppliers are assessed, including how on-site visits are conducted, how SNCRs (supplier non-conformance reports) are used, how often suppliers are periodically assessed, and shared the supplier expectations document along with the company business ethics policy. The industrial environment provided an incredibly rich context for the knowledgeable industrial guides and partners to holistically answer questions by connecting manufacturing theory and experience in strong relationships of ethics, resources, metrics, assessment, analysis, quality, reporting, documentation, and more. The commitment of the industrial guides to the students' learning was highly valuable.

This interconnection of delightful and deep learning through the industrial field trip experience was evident in case study experiences. During one field trip, the students were named in a company newsletter, welcoming them to the manufacturing facility and engaging them in the company culture. They were given a copy as a keepsake. Students also made comments during the field trip that revealed they were having fun learning:

- Student: "It feels like we're in a space station" (in an air-lock in the medical manufacturing facility)
- Student: "Can we have samples?" (at the medical manufacturing facility)

- Student: "Can I bring a friend?" (on a field trip). Note: the friend from another class attended.
- Student: "It always rains on Wednesdays" (field trips were on Wednesdays). Note: despite the rain, the average attendance on the field trips was 94%. There were no marks in the syllabus or assessment given for "participation." In each instance when a student could not attend the field trip, the student contacted the instructor beforehand and the assessment was modified. Each absence was for a valid reason.
- Industrial guide: "I commend your note-taking" (an industrial guide to the students)

These statements are reminiscent of Deming's "joy in learning." He wrote, "One is born with intrinsic motivation, self-esteem, dignity, cooperation, curiosity, joy in learning" [20, p. 122]. Here, it would seem from the student and industrial partner responses, industrial field trips offer the opportunity to re-discover this joy in learning. Field trips enable the students, teacher, and industrial partners to learn collectively in joy, in connectivity and context, and in depth. This echoes meaning, self-motivation, and ongoing curiosity—fundamental elements of lifelong learning.

In addition to the joy in learning statements, student engagement in learning was also evident in the case study field trips during Q&A sessions with the industrial guide(s), which lasted 45 minutes on average. Student attendance on the field trips was nearly perfect (only 4 times did a student miss a field trip), and in each instance the student contacted the teacher beforehand. An assessment was adapted for students with justified reasons for missing the field trip, which occurred in all 4 cases.

3.3 Results of the check and act phases

The field trip experiences and learning outcomes are further developed and tested in the Check phase when students complete authentic and aligned assessments. The students then revise their learning relative to the assessment based on formative feedback in the Act phase (via self, peer, and teacher). In the assessments and feedback, students are asked to draw out patterns, relationships, and connections from each learning loop into the next. There are seven learning loops related to the field trips in the case study. For the case study, the learning experiences (Table 4) and learning outcomes (Table 2) are tested in a range of learner-centred, authentic assessments outlined with corresponding forms of formative feedback in Table 5.

For the assessments in Table 5, 95.5% of them were fully completed by students and on time. In other words, of the 104 assessments in Table 5 (17 students $\times$ 6 assessments = 104), an assessment was only not submitted or submitted late 4 times. The course also included summative assessments (a midterm and a final exam), a final project that included self, peer, and teacher feedback with respect to rubrics created by students, and two assessments conducted prior to the field trips (one technical report and one reflection). Table 5 is specifically focused on assessments related to each field trip.

Formative feedback is essential to help connect each PDCA process with the next one in a continuous learning loop (as in Fig. 1). Concept maps are another tool that was used in the case study to draw connections between the field trip experiences and theories. Students were asked to draw the maps as a pop-quiz for the teacher to assess current connec-

Table 5. Field Trip Assessments and Feedback with Aligned Learning Experiences and Learning Outcomes

		Learning Outcomes								Formative Feedback			
Learning Experience	**Types of Assessment**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Self**	**Peer**	**Teacher**	**Average %**
Field Trip 1: Sand casting manufacturer of engine blocks	Technical report	X	X	X	X		X		X	S		R, C, L	64.4%
Field Trip 2: Injection molding manufacturer of automotive parts	Technical report	X	X	X	X		X		X	S		R, C, L	69.8%
Field Trip 3: Large job shop and fabricator of die sets, winches, mining cars, etc.	Technical report	X	X	X	X		X		X	S		R, C, L	78.6%
Field Trip 4: Medical manufacturer of tablets	Reflection	X	X	X	X	X					D, R	R, L	74.5%
Field Trip 5: Small shop machining custom parts	Short Inquiry	X	X	X	X	X					D, R	R, L	72.9%
Field Trip 6: Additive manufacturing studio	Short Inquiry	X	X	X	X	X					D, R	R, L	83.0%

S = Comments in the summary section of the technical report, R = A highlighted rubric, C = Comments throughout a document, L = A letter to student summarizing main points for areas of strength and areas of improvement, D = Comments in an online discussion forum.

tions that were being made or not made, and hence could be addressed. In the assessments in Table 5, students were asked to assess their own understanding in different ways, and in several instances suggest improvements to their learning experience (both by their own actions and how the field trips, classes, and assessments could be improved). Specific, formative feedback on the field trips in the case study was given after the fourth field trip, in order for the teacher to make adjustments for student learning. Students were asked: "What was your favourite tour and why?" Students anonymously and voluntarily submitted responses; a sampling of these responses is shown in Table 6 related to aiding learning (L), career planning (C), and practical experience (E).

Table 6 shows a variety of student comments on what they did and did not like about the field trips with different preferences to different tours. In the comments, students commented with respect to their own learning interests and career interests, establishing a personal relationship with their reflection. In addition, students gave recommendations for other tours (e.g. "maybe tours of composites industry might be included if possible, this will help students understand more about the composites material process") and other active learning methods (e.g. "the only thing which could be added into it is doing casting on our own")—projecting their learning forward.

Affective learning in the case study was captured in the comparison between a pre-assessment and post-assessment that asked students to voluntarily and anonymously answer: What do you like about manufacturing processes? What do you *not* like about manufacturing processes?" Furthermore, students were asked to compare their pre- and post-assessment answers: "Referring to the "getting to know you" handout on the first day, are the answers to the above two questions the same as when you started this class? Or have they changed? Why do you think they've stayed the same or changed?" The results of the pre- and post-assessments are summarized in Table 7.

The comparison of pre- and post-assessment responses indicates some changes in the students' attitudes and/or awareness of attitudes (e.g. "I found out more about what I like and what I am

Table 6. Student Responses on Their Favourite Field Trip and Why

Student Quote	L	C	E
"All tours were exceptional because they really give the students a good understanding of the course and manufacturing processes involved in it. It gives student a practical experience. . ."	X		X
"My personal favourite of the tours was [the medical manufacturer]. All of the tours were so beneficial to visually aid what was taught in class. [It] was my favourite because manufacturing is typically viewed as "dirty." This tour may change the outlook of people with this type of thinking and may bring them to consider a career in the medical manufacturing field."	X	X	
"[The foundry] seemed rushed and was very loud and dimly lit. Seeing [it] was interesting, but I don't feel that I learned a lot during the tour itself. [The plastics manufacturer] and [the fabricator] both seemed very welcoming and gave an insight into the business aspects of the company in addition to engineering. [The medical manufacturer] was also very interesting because it provided a different environment than automotive. I think this variety is very beneficial."	X		
"My favourite tour was the [medical manufacturer] tour. The reason for this was that it touched on the medical industry, which is what I am interested in. My general grievance with the tours was that the factory atmosphere is very depressing. This is very uncontrollable but still did not enjoy it. I also liked how there was a diverse sample of manufacturing processes and they were not just focused on automotive for example."	X	X	
"Favourite tour: [the medical manufacturer]. Liked the completely different atmosphere. Very different because it was very clean and everything was very strict (hair nets, coats. . .). Cool to see the packaging and labeling processes. . ."	X		
"I liked all the tours except the [medical manufacturer]. The [medical manufacturer] was rather boring and uninteresting to me. However, I enjoyed all the other tours just as much as each other and I learned and saw new things. To me, any industry that is related to the automotive and aerospace industry is interesting and I see myself working in one of these, but that's just me. . ."	X	X	

Table 7. Pre- and Post-Assessment Results in Attitudes towards the Subject (Manufacturing Processes)

Pre-Assessment Answers (13 students)	Post-Assessment Answers (13 students)
• First question: 13 different answers • Latter question: 5 students gave an answer, 1 student gave no answer, and 7 students stated a version of "not sure" or "I don't know."	• First question: 13 different answers • Latter question: 12 students gave specific examples, 1 student stated "nothing in particular", and 1 student stated "nothing so far"
Comparing Pre- and Post-Assessment Answers in the Post-Assessment	
• 42% of the students noted significant change in their attitudes and beliefs about manufacturing • 33% of the students noted that their attitudes and beliefs were the same • 25% of the students did not answer the question	

interested in from the factory tours''). Students revealed personal relationships to the learning (e.g. ''I feel that I learned something about myself and about how I want to work''). They also noted curiosity (e.g. ''I wanna learn more about additive manufacturing''). Further analysis on the answers to the two questions in the pre- and post-assessments showed that no two answers were alike. This highlights the difference between a change in attitude and the metacognition of a change in attitude. Thus, changes in attitude were potentially higher than students may have been aware of.

3.4 Synthesis of results and benefits

The benefits of the proposed framework for industrial field trips in engineering education are related to the research and case study results, summarized in Table 8.

In addition to the latter benefits category, community synergy, the types of tours offered in the case study in this research (Table 4) also highlight how an educational institution can be aligned with industrial strengths. Schools often offer certain engineering degrees and specializations because of local industry need. In turn, local industry offers unique environments to learn from and experienced personnel with specialized knowledge. This combines to offer indispensable pedagogical value in alignment with educational programs. Industrial field trips are a means to tap into this opportunity.

In this case study, several industrial specializations were capitalized on by visiting a distinct and highly automated Cosworth process of sand casting, an international leader in quality for vitamin manufacturing, and the world's largest supplier of die sets in a city with a rich history of highly successful and revered tool and die shops. Capitalizing on this synergy proved not only to provide a unique learning opportunity for students but also a valuable opportunity for industrial participants. As one company president stated, his company was ''proud to be involved with the University so future graduates can understand the opportunities our industry has to offer.'' By recognizing these strengths in industry, and its knowledgeable professionals, the university also built respect and goodwill between education and industry in the local community, which benefitted everyone involved and affected.

4. Future issues and present concerns

The approach to field trips presented in this research is a learner-centered approach. This is quite different than a teacher-centered approach. Thus, to facilitate field trips with the proposed framework, the teacher's awareness of the paradigm shift from teacher-centered to learner-centered is essential [27].

Another concern of this research is that it was not directly compared to a traditional method (e.g. pure lecturing). Literature has shown that one-directional learning is ineffective, e.g. [1]—the premise that began this research. Also, when comparing traditional versus progressive education, Dewey states, ''There is always the danger in a new movement that in rejecting the aims and methods of that which it would supplant, it may develop its principles negatively rather than positively and constructively. Then it takes its clew in practice from that which is rejected instead of from the constructive development of its own philosophy'' [19, p. 20].
The constructive development of the philosophy and methodology presented in this research, and

Table 8. Summary of the Benefits and Results of the Research

Benefits	Evidence in the Research Results
Student engagement	• Pre-assessment of student interest in field trips as a learning method (Fig.2) revealed unanimous student interest in field trips. • Average Q&A session during the field trip was 45 minutes. • Student attendance on field trips was nearly perfect (only 4 times did a student miss the tour), and in each instance the student contacted the teacher beforehand. • 95.5% of assignments (Table 5) were completed on-time.
Deep learning	• Learning outcomes spanned learning domains (performative, affective, and cognitive) and related to a range of complexity according to Bloom's Taxonomy (Table 2). • Variety of assessments tested and developed students' learning with respect to technical report writing, reflection, and short inquiry that was further developed with formative feedback from different sources, including self, peer, and teacher feedback (Table 5). • Post-assessment communicated that 42% of the students noticed significant change in their attitudes and beliefs about manufacturing. 33% of the students felt that their attitudes and beliefs were the same. 25% of the students did not answer the question.
Joy in learning	• Student statements acknowledged having fun in the field trip experience (§3.2) and industrial partner commitment revealed benevolence towards students and their learning (§3.2).
Community synergy	• Industrial partner altruism and commitment to the students' learning, such as the planning discussions beforehand (§3.1.5), an average 45 minute Q&A session during the field trip (§3.2), and extended communication beyond the field trip (§3.2).

Table 9. Summary of the Pedagogical Field Trip Goals and the Results of the Research

Goals From Literature	Evidence in the Research Results
Social and affective learning [5, 10, 11]	• Established student awareness of, and concern for, industrial health and safety (§3.1.3). • Investigated students' predispositions to the industrial environment (§3.1.4). • Pre- and post- assessments asked students what they do and do not like about the industrial environment (manufacturing) and differences between pre- and post-assessments (Table 7). • Students drew personal relationships with their field trip experiences (e.g. what field trip they liked and why (Table 6)).
Holistic learning in a dynamic system [2, 3]	• Students developed learning outcomes in relation to the industrial context's interconnected web of people, materials, machines, processes, products and the broader environment revealed through themes offered by the industrial environment (Table 4). • Aligned learning outcomes (Table 2), learning methods (e.g. field trips, Table 4), assessments and formative feedback (Table 5)—constructive alignment (Table 1).
Long-term memory and learning anchors [12, 13]	• Used field trips as a learning anchor to relate theory (discussed in class) and experience (from the field trip), connected in discussions and assessments (Table 5).
Embedded in a longer learning process [14]	• Connected Dewey's experiential continuum [19] and Deming's PDCA cycles [20] (Table 1) in the methodology to create continuous learning loops (Fig. 1). • Results presented in the PDCA cycle (§3).
Clear curriculum links [15] and clear purpose [8]	• Related learning outcomes to CEAB graduate outcomes (Table 3). • Aligned learning outcomes (Table 2) to each field trip (Table 4) with an assessment and formative feedback (Table 5)—constructive alignment (Table 1).
Involve preparation and follow-up [7]	• Planned (§3.1) by defining learning outcomes and aligning them to curriculum (§3.1.1), assessing if field trips were an appropriate learning method for the class (§3.1.2), preparing students for health and safety (§3.1.3), investigating students predispositions to the industrial environment as a learning setting (§3.1.4), and additional planning (§3.1.5)—all with respect to an intentional pedagogical methodology (§2). • Assessments followed up with formative feedback (Table 5), also post-assessments (§3.3).
Active learning [9]	• Students brought two questions with them on each field trip (reflecting on theory first), gathered evidence and information from the industrial setting, compared this with theory and engaged critical thinking by reporting their findings in the assessments (Table 5). • Active learning methods were utilized in class (e.g. discussion mentioned in §3.1.4). • Students expressed further ideas towards active learning in the post-assessment (e.g. additional hands-on activities).

tested via case study, aligns itself with the affirmative success and learning evident in other pedagogical field trip literature. These goals set by the literature are aligned with the results of the research in Table 9.

While the benefits in Table 9 are encouraging, there is always room for continuous improvement. No PDCA cycle would be complete without a reflection forward into the next learning loop. Potential research questions include the following. How could learning the theory related to the field trips be made more active? For this research, active engagement of the students focused primarily on the field trips but learning theory could be made more active. How could further discussion be encouraged (e.g. informal amongst students after class, in-class, etc.)? Etc.

5. Conclusions

The proposed pedagogical framework synthesizes Dewey's experiential continuum pedagogical philosophy with Deming's plan-do-check-act (PDCA) iterative learning process. These PDCA cycles align the pieces of constructive alignment (learning experiences, learning outcomes, and assessment) into continuous improvement learning loops. This pedagogical framework, applied in a Manufacturing Processes Design course of 17 undergraduate, industrial engineering students, demonstrates positive results. Results of the proposed pedagogical framework establish learning strengths, such as: student engagement, deep learning (including affective learning), joy in learning, and community synergy. The results align with the goals of prior pedagogical literature on field trips and evidence the achievement of these goals through the case study. The proposed pedagogical framework for industrial field trips hence begets: social and affective learning, holistic learning in a dynamic system, long term memory and learning anchors, field trips embedded in a longer learning process, clear curriculum links and clear purpose, preparation and follow-up, and active learning. By integrating pedagogical methodologies in concert with best practices in existing field trip literature, the proposed framework lends a systematic approach for industrial field trips in engineering education that ensures valuable learning experiences for students, faculty, and the industrial community.

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