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Curriculum and Pedagogy in STEM Teacher Education: Developing Case Studies Focusing on Socio-scientific Issues and Differentiated Instruction

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ABSTRACT

Differentiated instruction (DI) is a teaching approach that aims to achieve learning for students of diverse backgrounds, abilities, and interests. This study explores STEM teacher candidates' (TCs') development of DI-focused curriculum using case studies of socio-scientific issues (SSI). The paper addresses the following research question: How well suited are case studies of socio-scientific issues to incorporate differentiated instruction? The paper adopts a qualitative method approach utilizing document analysis, in which the authors present the analysis of seven case studies of SSI developed by 18 TCs. Overall, the results convey that TCs showed very good integration of DI principles and practices in the case studies. TCs differentiated the process of teaching most followed by the product of learning; yet showing a need for more training in content differentiation to attend to students' needs, backgrounds, and academic levels. Furthermore, the research highlights the compatibility between DI and case studies of SSI, rendering them as promising tools to differentiate instruction. This research equips science teachers and curriculum designers with practical resources and strategies to implement DI, to ensure equitable education for all students. Implications for STEM teacher education research and practice are also highlighted.

Keywords: differentiated instruction, STEM education, teacher education, case studies, socio-scientific issues

Introduction

Classrooms are hubs for students from diverse cultural backgrounds, socioeconomic status (SES), gender, and race. Students' various academic achievement levels, interests, and needs add another layer to this diversity in student body. This matter is of unique importance in science, technology, engineering, and mathematics (STEM) disciplines. Yet, research still documents lack of equitable representation of women and racial minorities in STEM (Butler-Barnes et al., 2021; Salmon, 2022; Zuo et al., 2020). Accordingly, calls have been rampant to implement equity, diversity, and inclusion (EDI) measures in academic institutions, especially in STEM classrooms (Hernandez et al., 2013; Mark et al., 2020; Meyer & Crawford, 2011; Smith et al., 2022; Zuo et al., 2020). At a classroom level, examples of inclusive pedagogical strategies include differentiated instruction (DI) (Tomlinson, 2001) and universal design for learning (UDL) (Center for Applied Special Technology [CAST], 2022).

Correspondingly, recent science curriculum development efforts emphasize the importance of active learning and problem-based strategies (Gorghiu et al., 2015; Nguyen et al., 2021). One example

of these strategies in science classrooms is developing case studies of socio-scientific issues (SSI) (DeCoito & Fazio, 2017). This research aims to support STEM teacher candidates (TCs) in curriculum development that is focused on inclusive instructional approaches such as DI. In this study, TCs develop curriculum using case studies of SSI in a STEM curriculum and pedagogy course in the teacher education program at a Canadian university, in an attempt to promote the incorporation of EDI strategies in their future teaching practices.

Research Rationale and Questions

The integration of SSI in STEM curricula is crucial for promoting students' socio-scientific awareness of the social, political, and economic dimensions to science and situating science as accessible to various underprivileged groups (Chowdhury, 2016; Cook & Buck, 2013). Johnson et al. (2020) highlighted how SSI can promote learners' argumentation skills including reasoning, supporting claims, and the ability to question the sources of information. Hence, it is recommended that teacher education programs make explicit efforts to develop these skills by providing TCs a variety of experiences to develop their repertoire of SSI contexts and teaching strategies (Johnson et al., 2020) as well as SSI-related assessments (Stouthart et al., 2023). In line with these pedagogical recommendations, case studies allow for multiple levels of analysis and interpretation (Levin, 1995) and present various perspectives of different stakeholders. This is one of the main reasons case studies are adequate strategies to teach about SSI (DeCoito & Fazio, 2017).

Correspondingly, there are many benefits of DI, including enhancing students' appreciation, recognition, acceptance, understanding, and respect for individual differences among each other (Watts-Taffe et al., 2012). Thus, the benefits of DI provide a strong rationale for using case studies of SSI as vehicles to highlight diversity and differentiate instruction. However, two of the main challenges that hinder teachers' implementation of DI are limited curriculum resources and perceived complexity due to insufficient or ineffective training programs (de Jager, 2017; Turner & Solis, 2017; Wan, 2017). These reported challenges call for better teacher preparation in DI, with a focus on developing relevant instructional resources that can facilitate implementing DI in the classroom.

Accordingly, this research explores the compatibility of case studies of SSI and DI. It presents STEM TCs' development of science curriculum using case studies of SSI, with a focus on DI as a teaching approach. Therefore, this research aimed to address the following research question: How well suited are case studies of socio-scientific issues to incorporate differentiated instruction?

Literature Review

Case Studies as a Teaching Strategy

A case study is a description of a real-life situation that usually involves a decision, a challenge, an opportunity, a problem, or an issue faced by a person or an organization (Ching 2014; Leenders et al., 2001). The practice of using cases as a pedagogical tool is widespread in several fields such as law, business, medicine, and education. Case studies are used in a flexible manner that involves learning by doing, and hence engages students in active learning (Popil, 2011). In addition to teaching science content, case studies develop higher order thinking skills, critical thinking, collaborative work, communication skills, and decision making (Farashahi & Tajeddin, 2018; Mahaffey, 2019).

The effective use of case studies in teacher education has been documented (e.g., Ching, 2014; Hemphill et al., 2015; Koehler et al., 2019; Lengyel & Vernon-Dotson, 2010). Ching (2014) indicated that case studies are an important pedagogy in the training of TCs as it promotes critical thinking, decision making, and motivation. Hemphill et al. (2015) highlighted how case studies contribute to TCs' engagement and cognitive growth as they consider multiple sources of knowledge. Koehler et al.

(2019) also explored how case study discussions promote TCs' problem-solving skills and cognitive levels. Furthermore, DeCoito and Fazio (2017) maintained the importance of TCs designing and enacting case studies while they assume dual roles of curriculum developers and co-constructors of knowledge. Yet, to attain these benefits, teachers using case studies must consider the following: 1) contextualizing the case in real-life scenarios to make it memorable for students (Ching, 2014); 2) promoting peer interaction to internalize cognitive processes and gain new perspectives (Levin, 1995); and 3) facilitating and supporting the scaffold process by providing feedback and guidance (DeCoito & Fazio, 2017). These considerations were incorporated within the instructions provided to the TCs as they developed their case studies in this research.

Case Studies of SSI

Socio-scientific issues are science issues that have a significant effect on society (e.g., nuclear energy, biotechnology, human genetics, global warming) (Sibiç & Topçu, 2020). Socio-scientific issues involve societal dilemmas with conceptual, procedural, or technological links to science (Sadler & Zeidler, 2004). Socio-scientific issues also acknowledge the contextual setting in which science is embedded, hence, they can provide a rich medium for argumentation due to their societal, political, and ethical implications (Bächtold et al., 2022; Hancock et al., 2019; Sadler, 2009; Zeidler et al., 2009).

DeCoito and Fazio (2017) emphasized the suitability of case studies as a pedagogical tool to specifically address SSI in science education. Case studies allow learners to debate about the nature of science topics (McComas, 2020), and to teach about the history and philosophy of science (HPS) (Höttecke & Riess, 2009; Stinner et al., 2003). Moreover, Höttecke and Riess (2009) note the importance of teaching about HPS via case studies as they include student perspectives as well as creative, open-ended, and student-centered activities like experimenting, making observations, discussing, and role-playing.

Levinson (2006) argue that teaching SSI requires a strong theoretical and conceptual basis and presents a model for teaching these topics. Levison's model includes three categories: 1) reasonable disagreement which includes evidence-based discussions and high level of critical thinking; 2) communicative virtues that include tolerance, respecting differences, thoughtful listening, equality, and freedom of expression among many other elements; and 3) modes of thought that include narrative modes and logico-scientific modes based on scientific evidence. These assertions justify the alignment between SSI and the philosophy behind DI; thus, providing a strong rationale for using case studies of SSI in diverse classrooms, and specifically for incorporating DI as an inclusive pedagogical practice.

On the other hand, Mostert (2007) highlights some of the challenges that TCs may face when teaching using case studies, including pedagogical ones, such as their unfamiliarity with the strategy and difficulty matching case problems to course content. Additionally, Şen Akbulut and Hill (2020) shed light on another pedagogical challenge especially in the context of using case studies to teach SSI. The authors highlight the difficulty of tackling controversial issues and the importance of being careful, well-prepared, and considerate about students' backgrounds upon bringing these issues into the classroom. Mostert (2007) adds practical challenges that TCs face upon teaching using case studies such as time, physical setting for the discussion, lack of experience, and lack of modeling skills (Mostert, 2007). Sibic and Topcu (2020) indicate that TCs generally do not have enough self-efficacy beliefs to integrate SSI into their curriculum, hence their call for incorporating SSI in teacher education programs. Hancock et al. (2019) maintain that several factors affect teachers' choice of SSI such as their passion and existing resources. Moreover, Chang and Park (2020) highlight the importance of professional development that aims at specifically advancing teachers' pedagogical content knowledge to teach SSI. Thus, including these topics in teacher education programs is crucial in preparing STEM teachers to incorporate them in their future practices.

Therefore, given the aforementioned affordances and challenges of developing case studies of SSI, this research aimed to provide TCs with a first-hand experience in developing case studies of SSI and simultaneously incorporating DI as an inclusive pedagogical practice in their curriculum.

Theoretical Framework

Differentiated Instruction

Differentiated instruction is a constructivist-based teaching approach that aims to achieve learning for all students by meeting their personal learning needs (Valiandes & Tarman, 2011). Deunk et al. (2015) explained differentiation as a combination of teachers' attitudes, knowledge, practices, and professional skills needed to provide adaptive instruction to address student differences. Tomlinson (2001) simplified the areas that teachers need to differentiate as three main categories: 1) content- what is taught, 2) process- teaching strategies, and 3) product- assessment strategies.

Although DI is extensively researched and theorized (e.g., Tobin & Tippett, 2014; Tomlinson et al., 2003), Maeng (2017) documented the need to explore the applicability of DI in STEM subjects at the secondary school level. Moreover, one of the significant gaps is research on DI in a Canadian context, despite student diversity in Canadian classrooms. In Ontario specifically, minimal research is dedicated to teachers' understanding and implementation of DI, as well as their preparation to implement it. For instance, D'Intino and Wang (2021) indicated that teachers in Canadian classrooms need more support to be able to differentiate their instruction. Specht et al. (2016) reiterated the specific need of secondary school level TCs to be trained on inclusive teaching strategies such as DI. Therefore, this research is warranted as it addresses the gaps related to secondary STEM teachers' preparation focusing on DI, including TCs' DI-focused curriculum development.

The DI Matrix

To analyze how TCs incorporate DI in case studies, the authors adopted the Differentiated Instruction Implementation Matrix-Modified (DIIM-M) (Maeng, 2011) after obtaining the permission from the author. The DIIM-M is a validated instrument that evaluates teachers' proficiency and their performance levels in DI (Downes, 2006, as cited in Maeng, 2011). Since the instrument was initially designed to assess the implementation of DI in a classroom, several modifications were made to address the uniqueness of the planned case studies, and hence named DIIM-M2. The resultant matrix is composed of six domains and 20 sub-criteria. See Table 1 for details pertaining to the modifications of the original matrix are explained in the "Data Analysis" section. This matrix will be referred to as the DI Matrix for simplicity.

Table 1

Short Version of the DI Matrix (DIIM-M2)

Domains	Criteria	Criteria Description
1: Quality Curriculum and Lesson Design	1. Quality and clarity of the lesson objectives: What students should know, understand, and be able to do	Objectives are informed by national or state standards and the important ideas, issues, or problems specific and meaningful to the content area. Objectives extend learning in authentic ways.

Domains	Criteria	Criteria Description
	2. Alignment of lesson objectives and lesson activities throughout the case study	The activities of the lessons are clearly and strongly related to the objectives.
2: Response to Learner Needs	1. Preassessment and Proactive Preparation	The case study demonstrates that the TC used multiple sources of preassessment data and student learning profiles in advance of the lessons to plan for the needs of the students.
	2. Scaffolding for Struggling Learners; Special Ed., ELL, etc.	Struggling learners are given tasks of high-quality and thoughtfulness with appropriate scaffolding to reach the same learning goals as other students. Multiple indicators are used when grouping students so that struggling learners experience a variety of grouping strategies.
	3. Challenging Advanced Students	Academically advanced students are appropriately challenged at higher levels of complexity and quality, not quantity. Experiences as an academic anchor in a flexible group enhance their understanding. Options are available for compacting into independent study on the topic.
3: Planned Instructional Practices	1. Lesson Organization	The lessons are organized in a coherent (organized, unified, and sensible) manner, producing a unified whole.
	2. Modes and Strategies of Instruction	The lessons use multiple modes of instruction that require active learning and the exploration of the lessons' understandings. It intentionally matches the learning profiles and the learning needs of the students. The strategies and activities reflect best practices in that content area.
	3. Engagement Capacity of Activities	Lesson components are stimulating, motivating, and engaging to learners, linked to students' prior learning or experiences, and clearly connect to their lives and/or goals. Students explicate connections between lesson content, practical applications, current events, the real world, or other aspects of the content area.
	4. Intellectual Development	Each student works at levels of readiness, interest, and/or learning profile that are appropriately challenging. The lessons are designed so that all students are compelled to do their best and complete high-quality work. The strategies and activities are planned to promote higher order thinking for all students.
	5. Flexible Grouping	Lessons use various student groupings: individual, pairs, small groups. Students are grouped for a great variety of reasons to differentiate content, process, and/or product by readiness, interest, and/or learning profile. The lessons may combine grouping rationales (i.e., readiness and interest). Flexibility in grouping strategies is in response to a clear analysis of student needs.
	6. Teacher's Planned Role, Learner Independence, and Student Choice	Teacher's overall planned role is primarily that of coach or facilitator in learning. Both students and teacher will have consistent input into lesson content. Students take on increasing responsibility for their own learning. There is a perfect balance of student and teacher choice.
	7. Technology Integration	The TC plans an excellent use of digital material. The lessons can be fully implemented in an online environment.
4: Student Assessment	1. Formative Assessment	TC plans to regularly use formative assessments throughout the lessons. Data from these lessons is used to: make modifications to instruction within a lesson, to gauge student understanding, and to plan future instruction for individuals and groups.

Domains	Criteria	Criteria Description
	2. Existence and Quality of Rubrics and Guidelines	Rubrics and guidelines of clearly articulated assessment criteria and standards are developed. Students have the ability to participate in the creation of the rubric and guidelines and can actively plan next steps for learning.
5: Positive, Supportive, and Inclusive Learning Environment	1. Principles of Equity, Diversity, and Inclusion (EDI) as stated in Ontario's Education Equity Action Plan (Ontario's Education Equity Action Plan, 2017)	The case study demonstrates a sophisticated understanding of EDI principles. The case study excellently implements inclusive and culturally responsive pedagogy. Planned lessons fully reflect and attend to diversity in students' identities.
	2. Respectful Behavior Toward and Among Students	The lessons' structure fosters active participation and questions from all students. Awareness of students' strengths, successes, and contributions are cultivated and celebrated.
	3. Sense of Community and Collaboration	Students and teacher can consistently focus on both individual and group excellence and growth. Students can consistently engage and support one another in learning. They are supported to work with any other student in the class.
Domain 6: Evidence of Differentiation	1. Content: adapting what is taught and modifying how students are given access to the information (Tomlinson, 2001)	Lessons are highly concept-based and makes use of diverse materials at various levels of readability, complexity, and/or interest. Lessons include, but are not limited to, one or more of the following strategies: multiple ways to access and organize information, learning contracts, curriculum compacting, flex-group mini-lessons, and varied support systems such as audio/video recorders, note-taking organizers, highlighted print materials, digests of key ideas, peer/adult mentors.
	2. Process: the sense-making… without it, students either lose the ideas or confuse them (Tomlinson, 2001)	Most of the instructional time is spent on small groups of students or individuals working with various sense-making activities that represent a diversity of approaches at varied degrees of sophistication to be completed in varying time spans with various levels of scaffolding. All sense-making activities use essential skills and essential information to understand the big idea or understanding of the lesson. The lesson's sense-making activities may differentiate in one or more of the following ways: readiness by matching complexity of task to student's current level of understanding; interest by giving students choices and linking to personal interests and/or goals; learning profile by making sense of ideas in the students' preferred way of learning.
	3. Product: helps students rethink, use, and extend what they have learned… [and] represent understandings (Tomlinson, 2001)	Case study provides several product options that are designed to foster deeper and richer understandings of the unit's goals. Products may differ due to curriculum requirements or student readiness, interest, or learning profile. Guidelines provide the perfect balance between structure needed to focus and guide students and freedom to support innovation and thought. Students collaborate with the teacher to design the project requirements, timeline for completion, and assessment criteria. Teacher works as a coach to facilitate, scaffold, and expand the students' thinking through flexible study groups, mini-lessons, and conferencing.

Methodology

This research explores TCs' development of DI-focused curriculum in a STEM curriculum and pedagogy course in a teacher education program at a Canadian university. In this paper, the authors adopted a qualitative method approach (Creswell & Creswell, 2018) utilizing document analysis (Stake,

2000), to capture the complexity and the richness of how STEM TCs developed curriculum to be inclusive of DI using case studies of SSI.

In this paper, the authors present the analysis of one course assignment – case studies of SSI developed by TCs. Document and artefact analysis produces rich descriptions of a single phenomenon, event, organization, or program (Stake, 2000). Yet, few limitations may decrease its authenticity and accuracy. First, the chosen documents may be personal (written by the teachers themselves) and biased/self-selected; hence they may not be representative or trustworthy. Moreover, the information presented by the participants for analysis may be insufficient, incomplete, irrelevant, or un-understandable (Merriam & Tisdell, 2015). To avoid these limitations, all TCs' course work related to this assignment, including lesson plans, supplementary teaching and assessment resources, and peer presentations were analyzed as part of the collected evidence.

Participants

In total, 18 TCs participated in the study. Participants were enrolled in a *STEM Curriculum and Pedagogy* course in the second year of the teacher education program at a university in Ontario, Canada. In year one of the teacher education program, TCs had enrolled in 10 courses. Among these courses are those directly related to general teaching methods: one course on special education and inclusion, one course on Aboriginal education, two teaching methods courses (each related to one of their future teachable subjects), and one course entitled Year 1- Introduction to STEM education. In year two of the program, TCs were enrolled in seven courses. Among these courses are those directly related to general teaching methods: one course on supporting English language learners, one course on multiliteracies, and one course entitled Year 2- Curriculum and pedagogy in STEM education, in which this study was conducted. Accordingly, TCs have had background knowledge in curriculum development (lesson and unit planning), SSI and their importance in science curriculum, and inclusive education. All TCs in the study were eligible to teach STEM subjects in the intermediate-senior divisions (Grades 9, 10, 11, and/or 12). TCs' teachable subjects included general sciences, biology, mathematics, physics, chemistry, health and physical education, and computer studies.

Overview of the Course Procedures

This 12-week course is one of two STEM courses offered to TCs enrolled in the STEM Specialty Focus in the teacher education program. The course was enriched with DI resources and training. In the first two weeks of the course, the researcher coordinated with the course instructor and provided a seminar on DI and EDI in the context of STEM education. Throughout the course, the instructor addressed DI in an explicit and reflective approach (Abd-El-Khalick & Lederman, 2000). The instructor provided the TCs with DI resources and required the TCs' to integrate DI principles and strategies in their assignments as one of the success criteria. Hence, TCs were requested to explicitly address DI in their coursework (Estaiteyeh & DeCoito, 2023b, 2023c).

Additionally, the instructor provided feedback on TCs' work and recommendations on how to improve or maintain certain aspects of their assignments. For example, in class discussions the feedback took the form of guiding questions to draw TCs' attention to the inclusion of DI practices. The instructor would ask TCs how they plan to include DI in a specific lesson plan or how plan to include more culturally relevant pedagogies in their content and strategies. When TCs submitted a draft of their work, the instructor would include links to articles or resources that TCs could consult and incorporate as they see fit. As such, the ongoing feedback was eye-opening and generic to enhance the quality of the work. Moreover, TCs were constantly reflecting on their progress and hence advancing their knowledge and skills in DI implementation throughout the course.

Data Sources

In groups of four, TCs designed a case study, assuming dual roles – curriculum developers and students (DeCoito & Fazio, 2017). This assignment was the first major task for TCs in the course. Over a five-week period, a team of four TCs collaborated to develop a case study that is interactive and based on SSI (e.g., environmental sustainability, healthcare, social issues, etc.), for Grades 9-12. At the beginning of the five-week period, the instructor explained the theoretical and conceptual backgrounds related to case studies of SSI and discussed what comprises this task. In addressing the SSI, TCs were required to complete several activities that involve the research and development of the case study including lesson plans, scenario, stakeholders, graphic organizers, note-taking framework, consequence map, cost-benefit analysis, and a presentation to lay audience. The task was also accompanied with progress reports, peer feedback, and a final reflection. A sample cover page of this assignment is illustrated in Figure 1.

Figure 1

Sample Cover Page of a Case Study about Light Pollution

A total of seven case study packages were completed and comprised the data set analyzed. The data set included 18 lesson plans, supplementary teaching and assessment resources, and peer presentations. Each team of TCs submitted all those artefacts and documents as a case study package, which was the unit of analysis in this research.

Data Analysis

Data analysis adopted a deductive approach in which the DI Matrix shown in Table 1 was utilized for the content analysis of the case studies. The deductive analysis looks back at the data from pre-determined themes (Creswell & Creswell, 2018). The data analysis process included three steps.

First Step: Developing the DI Matrix

As introduced earlier, the DIIM-M (Maeng, 2011) was adapted then used to analyze how TCs integrated DI in their case studies. First, some of the criteria that are unique to in-class observations were removed since our analysis is restricted to what the TCs planned but did not implement in the classroom. Second, due to the COVID-19 pandemic, TCs in this research were expected to conduct their practicum in an online environment as they may be teaching online in the future. To highlight the importance of this aspect, a specific criterion was added regarding integrating technology and the ability to implement the case study in an online environment.

Furthermore, one of the major amendments to the matrix was the explicit incorporation of EDI principles within the framework. This amendment was done by adding a criterion entitled "Principles of EDI", as stated in Ontario's Education Equity Action Plan (2017) within Domain 5, which entails implementing inclusive and culturally responsive and relevant teaching, curriculum, assessment, and resources. This action was to ensure that students consider Ontario's Education Equity Action Plan (2017), which promotes classes that are inclusive and reflect student diversity. This change takes into consideration the recommendation by Valiandes et al. (2018) calling for the blending of intercultural education and DI in practice by deploying the strategy of interculturally differentiated teaching. Moreover, since the STEM TCs are most likely going to teach in Ontario schools, Ontario's Education Equity Action Plan was the most relevant framework to integrate in the matrix. Therefore, the resulting DI Matrix- composed of six domains and 20 sub-criteria, is a composite model adapted by the researchers to analyze the case studies specifically with an attention to DI integration and Ontario's equity policies.

Second Step: Deductive Analysis Using the DI Matrix

The case studies were analyzed in a descriptive manner to explain the level of integration of different DI components. To ensure the reliability and validity, the authors conducted an iterative and collaborative analysis process (Creswell & Creswell, 2018). The first author conducted the analysis of the case studies as per the criteria in the matrix, and the second author reviewed it by providing comments and corrections. The two authors met afterwards to discuss and finalize the findings.

Third Step: Quantification

The qualitative analysis was quantified to further explore the holistic incorporation of DI across all case studies. Quantitizing (Sandelowski et al., 2009) was done by providing scores for each case study on each of the DI Matrix criteria and domains to attain a deeper understanding of TCs' successes, and the areas of improvement with respect to their utilization of DI in their curriculum development.

A score out of four was allocated to each of the 20 criteria in the DI Matrix, where (1) indicates "Novice", (2) indicates "Apprentice", (3) indicates "Practitioner", and (4) indicates "Expert". This score allocation was followed by the following calculations:

1) The total score of each case study on the DI Matrix (score out of 80) is the sum of the scores obtained by the case study on all the 20 criteria in the matrix.
2) Average score of the case studies on each criterion (score out of four) is calculated by dividing the sum of the scores of all seven case studies on an individual criterion by seven (the total number of case studies)
3) Average score of the case studies on each domain (score out of four) is the average score of the criteria within each domain. For example, the average score of the case studies on Domain 1 is obtained by calculating the average of the scores on its two criteria (explained in step 2 above).
4) Average score of the case studies on each domain in percentage is the number obtained in step 3 converted to percentages (dividing by four and multiplying by 100).
5) The count of case studies scoring a specific level on each of the DI Matrix criteria, that is, how many of the seven case studies scored 1=Novice, 2=Apprentice, 3=Practitioner, and 4=Expert on a given criterion.

Results

A General Analysis of Groups' Performance

Table 2 describes the case studies created by TCs, including a brief and general analysis listing the major positive points and missing elements, as well as the total score obtained on the DI Matrix.

Table 2

Case Studies' Details and Brief Analysis

Case Study Title	Class and Subject	Case Summary	Brief Analysis
Health and Medicine			
Case Study A: COVID-19 and the Vaccine Race	Grade 12: Science	Explore the implications of producing and distributing a COVID-19 vaccine in Canada from the perspectives of four key stakeholders: pharmaceutical companies (for), medical ethics advisory board (against), parents (against), and public health officials (for).	The case study scored 59 out of 80 on the DI Matrix. TCs did well on integrating multimodalities and using flexible grouping. TCs also related their topic to EDI principles by including equity issues in relation to vaccine distribution, as well as Indigenous ways of knowledge when discussing Western science. On the other hand, the case study did not scaffold learning for struggling learners or challenge advanced students. More variety in assessment strategies and clarity about assessment criteria are also recommended. Thus, differentiation of content and product components needed improvement.
Space Science			
Case Study B: Starlink	Grade 9: Earth & Space Science	The pro-Starlink and anti-Starlink groups assemble and plan out a case for debate. The stakeholders are SpaceX (satellite manufacturer), consumers (rural and under-serviced communities), professional astronomers, and space explorers.	The case study scored 58 out of 80 on the DI Matrix. TCs did well on their lessons' organization and aligning objectives with instructional activities. They incorporated rubrics in their assessment. Moreover, they encouraged collaboration and respectful behavior among students. On the other hand, the case study did not highlight topics related to EDI principles. Their differentiation strategies in content, process, and product aspects were limited.

Case Study Title	Class and Subject	Case Summary	Brief Analysis
Environment			
Case Study C: Water Crisis in Canadian Indigenous Communities	Grade 10: Science	The decision of whether to upgrade the existing water treatment facility in Grassy Narrows First Nation Community is decided after a debate between various stakeholders at a town hall. The stakeholders are government, environmentalists, utility companies, and the Indigenous community.	The case study scored 65 out of 80 on the DI Matrix. TCs did well on diagnostic assessment of their students at the beginning of the case; varying the modes and strategies of teaching; using flexible grouping; proficiently integrating technology in their teaching; and using formative assessment. Moreover, the chosen topic relates to equity practices in Indigenous communities. This content would catalyze many discussions on topics related to EDI principles. The case study did not scaffold learning for struggling learners or challenge advanced students. Furthermore, the case study could have been more consistent in implementing the aforementioned positive strategies throughout all lessons.
Case Study D: Microplastics	Grade 11: Biology	The costs and benefits of plastic use are investigated, based on perspectives of four stakeholders: plastic manufacturer, consumers of plastics, scientific researchers, and ocean protection groups.	The case study scored 70 out of 80 on the DI Matrix. TCs did well on diagnostic assessment of their students; varying the modes and strategies of teaching; using flexible grouping; and using formative assessment. TCs did not scaffold learning for struggling learners or challenge advanced students. Furthermore, EDI principles were not consistently incorporated in all lessons.
Case Study E: Light Pollution – The Effects of Artificial Light Use	Grade 10: Science	The case explored the social-scientific issue relating to artificial light use and the effects of light pollution, from a variety of stakeholder perspectives, taking on a social, economic, and environmental views.	The case study scored 74 out of 80 on the DI Matrix. TCs effectively addressed all three aspects of DI: content, process, and product. The case study could be improved by enhancing technology integration and being more consistent in challenging advanced learners and scaffolding learning.
Case Study F: Three Gorges Dam	Grade 9: Science	Discuss the implications of the Three Gorges Dam. The stakeholders are: The Chinese government, dam builders/hydro power companies, farmers forced to relocate, and environmentalists	The case study scored 76 out of 80 on the DI Matrix. TCs effectively differentiated all the aspects in their lessons. TCs could better align the objectives with the instructional activities, and challenge advanced learners.
Case Study G: Societal Impacts of Nuclear Energy – Building a Nuclear Power Plant	Grade 11; Physics	Decide on whether constructing a nuclear power plant in Innergee, a little-known Ontario town, would impact on the community. The town hall involves speakers representing major stakeholders in this decision.	The case study scored 66 out of 80 on the DI Matrix. TCs addressed differentiating the process of the lessons by using a variety of engaging activities. TCs neglected to clarify the objectives, differentiate the content, ensure more student agency, and provide clarity on assessment criteria and rubrics.

A Detailed Analysis of the Case Studies

Seven case studies were analyzed according to the DI Matrix and included accompanying lesson plans, presentation, supporting documents and resources. This section details how TCs addressed each of the criteria in the DI Matrix, with a focus on best practices.

Domain 1: Quality Curriculum and Lesson Design

The first criterion in this domain includes what students should know, understand, and be able to do. To attain the expert level, the case studies' lesson objectives should comply with the written curriculum standards (Ontario Ministry of Education, 2008), and the important ideas, issues, or problems specific and meaningful to the content area. The objectives need to extend learning in authentic ways. TCs showed excellent implementation of this criterion with three case studies reflecting scores at an expert level and four case studies at a practitioner level. With respect to the second criterion, the activities of the lessons within the case study need to be clearly linked to the objectives. TCs also showed excellent implementation of this criterion with four case studies showing an expert level and three case studies showing a practitioner level.

In general, TCs showed a mastery of this domain. Most TCs were able to address the case study-related skills as well as the learning goals and science content objectives. For many case studies, the four required lessons provided opportunities to address many objectives, hence offering rich science content. Yet, few TCs focused more on the case study requirements such as note-taking, KWL charts, consequence maps, and cost-benefit analysis, rather than the science content. Most TCs were able to smoothly integrate the case study components within the lessons, and thereby use the case study as a tool to teach the science content.

Domain 2: Response to Learner Needs

First, to attain the expert level on the first criterion- preassessment, the case study should reflect multiple sources of preassessment data and student learning profiles in advance of the lesson to address and plan for student needs. In general, TCs showed a good level of implementation of this criterion with three case studies scoring at an expert level, three case studies at a practitioner level, and one case study at an apprenticeship level. For example, TCs frequently used pre-assessment and proactive assessment within formative assessment. They included brainstorming activities and referred to students' prior knowledge in their lesson plans, which demonstrates awareness of the importance of tackling students' prior knowledge and misconceptions through diagnostic assessments before introducing new concepts. On the other hand, some groups relied on graphic organizers (e.g., KWL charts) to explore students' prior knowledge. One group did not include a diagnostic assessment. Several groups did not show consistency in tackling students' prior knowledge throughout the whole case study and included this aspect in only one or two lessons. Samples of diagnostic assessment include the following statements:

> Find out what students know about clean drinking water in First Nations communities. Find out why a boil water advisory would be in effect. (Group C, lesson plan)

> To recap information from the preceding day's class, a "mind-on" activity must ensure the students understand earlier concepts before moving on to the next topic. (Group D, lesson plan)

The second criterion in this domain is scaffolding, specifically for struggling learners. To attain the expert level on this criterion, the case study must be inclusive, for example for special education students, English language learners (ELLs), and students with low reading abilities. Struggling learners need to engage with high-quality tasks, with appropriate scaffolding to attain the same learning goals as other students. In certain cases, individual educational plans (IEPs) need to be provided to certain students. Multiple indicators are used when grouping students so that struggling learners experience a variety of grouping strategies. Four case studies scored at an apprenticeship level, two at a practitioner level, and one at an expert level. Most case studies did not indicate any special arrangements in this regard. This criterion was superficially addressed through flexible grouping and the use of multimodalities. For example, one group included:

> Students are given the opportunity to read the case study on their own or have a PDF read out loud with their Chromebooks. This helps accommodate ELL students, who may have a difficult time with written material. The teacher can also provide students with the option to use a translator extension if they require one to read the case study. (Group F, lesson plan)

One group also included a voice-over option along with the provided text to students in a presentation, demonstrating more inclusivity to specific groups of students with special needs. Yet, TCs demonstrated a lack of awareness and consistency in addressing various student needs. Several groups referred to ELLs in their lesson plans which reflects an accepted level of awareness. Yet, there were no practical strategies planned to cater for their needs. An example of an incomplete adaptation is:

> Ask students with IEPs and ELLs how they find the lesson if they feel they need to go to resource or would like additional materials. (Group D, lesson plan)

In general, this criterion requires improvement. For example, none of the groups mentioned modifying the pace of learning for different groups of students or modifying the learning objectives at certain learning stages. Moreover, the adaptations were inconsistent throughout the same case study and thereby needing much reinforcement.

Finally, to attain the expert level on the third criterion- challenging advanced students, the case study must challenge high-achieving students at higher levels of complexity and quality, not quantity. Five case studies reflected scores at an apprenticeship level, two at a practitioner level, and none of the case studies scored at an expert level. The average score on this criterion was the lowest among all 20 criteria indicating that most case studies did not include special arrangements for challenging advanced students. Furthermore, most case studies did not mention this group of students. The arrangements included flexible grouping and independent research by students to reach a more in-depth understanding, yet worksheets, rubrics, and class activities did not address this category of students explicitly. While certain tasks enable students to work independently, and others require critical thinking, high achievers in general were not provided with multiple options to expand their knowledge. Thus, this is one criterion that needs to be further developed in the future.

Domain 3: Planned Instructional Practices

For the first criterion – lesson organization – to attain the expert level, the case study lessons and elements need to be organized in a coherent (organized, unified, and sensible) manner, producing a unified whole. TCs showed an excellent implementation of this criterion with six case studies scoring at an expert level and one at a practitioner level. In all case studies, lesson plans were clear and

comprehensive, well-organized, and easy to follow. As well, all lessons and activities were linked and connected appropriately.

For the second criterion – modes and strategies of instruction – to attain the expert level, the case study lessons and elements should utilize multiple modes of instruction that require active learning and exploration of student understandings. The lessons should intentionally match the learning profiles and the learning needs of students. As well, the strategies and activities should reflect best practices in that content area. TCs showed very good implementation of this criterion, with four case studies scoring an expert level and three at a practitioner level. For example, Group C used think-pair-share, a map visualization and analysis activity, video and picture analysis, note-taking activities, class discussions, online game activity, independent and group research, and a debate throughout their four lessons. Activities of Group B included videos, jigsaw, hands-on activities, drawing graffiti activity, class discussions, and group activities. Group D included labs, Kahoot activities, table group discussions, infographic analysis, debates, article analysis, and hands-on activities such as extracting microbeads. Thus, there was an evident utilization of multimodalities especially digital resources, a variety of student-centered activities, and inquiry-based instruction by all groups. On the other hand, two main points of improvement are consistency in integrating multiple tools throughout all lessons and avoiding long phases of direct instruction. One possible reason for prolonged direct instruction is the variety of new case study elements which TCs chose to introduce through teacher explanation.

For the third criterion – engagement capacity of activities – to attain the expert level, the case study lessons and elements should be stimulating, motivating, and engaging to learners; link to students' prior learning or experiences; and clearly connect to their lives and/or goals. Students should be able to explicate connections between lesson content, practical applications, current events, the real world, or other aspects of the content area. TCs demonstrated very good implementation of this criterion with four case studies scoring at an expert level and three at a practitioner level. The variety of activities presented in the case studies ensured high levels of student engagement. For example, lessons included hands-on activities, roleplay, demonstrations, digital games, online simulations, videos, mind maps, note-taking activities, infographics, group work, class discussions, think-pair-share, student independent research, debates, and jigsaw activities. Furthermore, the topics tackled by the seven case studies, and the questions raised, are highly linked to students' daily lives and real-world implications.

For the fourth criterion – student intellectual development – to attain the expert level, the case studies should enable each student to work at levels of readiness, interest, and/or learning profile that are appropriately challenging. The lessons should be designed so that all students are encouraged to do their best and complete high-quality work. The strategies and activities should promote higher order thinking for all students. TCs demonstrated very good implementation of this criterion, with three case studies scoring at an expert level and four at a practitioner level. Three major factors contributed to TCs achieving this level. The first factor is the inclusion of a variety of activities and case study components requiring students to engage different levels of thinking in each activity. Some activities require advanced levels of high order thinking skills such as critical thinking and evaluation. For example, Group C planned the following activities:

> Break the fake activity: Students will learn about criteria to assess online resources to determine the validity and reliability of the information. They will learn about two different methods of note taking while researching to help keep the information they find organized.
>
> Cost-Benefit Analysis: Ensure that students are using valid reasoning to create their cost and benefit values on a scale from 1 to 5 and the probability of the result occurring. Where possible, they should include references for the sources of their information.

The second factor contributing to implementation of this criterion is the 5E inquiry model, which requires students to explore content. Finally, the third factor is engagement in discussions and debates about a controversial topic from various opposing perspectives and viewpoints, thus requiring students to be prepared with different arguments that enhance their analytical and critical thinking skills. This argumentation also extends students' personal knowledge to a new context. For example, Group F stated the following in their peer presentation:

> The teacher should encourage students to consider opposing arguments in preparation for the debate during the research period (lesson 3). One way to do this is with a consequence map. If the claimant will open with, for example, a positive economic consequence for the Three Gorges Dam, a member of the opposition can use a negative economic consequence as part of their rebuttal.

Furthermore, student readiness is reflected in the depth of information they research and present to their peers, with higher performing students presenting deeper understandings of the subject matter. Also, students' interests were addressed by most groups who allowed students to choose the stakeholders they want to represent, take a stand, and defend it using their own arguments. This strategy ensures students relate on a more personal level and thereby contribute more so to the ongoing class discussions. On the other hand, the major notable point of improvement in this criterion relates to certain case studies in which students' roles are restricted to the application level rather than encompassing higher order thinking. Moreover, many TCs did not explicitly indicate how they would promote higher order thinking especially for high achievers. This result was discussed earlier in Domain 1.

For the fifth criterion – flexible grouping – to attain the expert level, the case study lessons should include various student groupings such as individual, pairs, and small groups, whenever applicable. Students are grouped for a great variety of reasons to differentiate content, process, and/or product by readiness, interest, and/or learning profile. The lesson may combine grouping rationales (i.e., readiness and interest), and flexibility in grouping strategies is in response to a clear analysis of student needs. TCs showed excellent implementation of this criterion, with six case studies scoring at an expert level and one at a practitioner level. All case studies included a variety of independent work, think-pair-share, group work, and general class discussions across the lessons. The last lesson in all case studies also included a debate (e.g., fishbowl debate) or a townhall between students to discuss and present their viewpoints. Moreover, several groups stated that they would change the group members' composition throughout the case study to ensure more student interaction and exchange of ideas.

For the sixth criterion – teacher and student roles – to attain the expert level, the case studies need to ensure that the teacher's overall planned role is primarily that of coach or facilitator. Both students and teacher need to have consistent input into lesson content, with a balance of student and teacher choice, with students taking on increasing responsibility for their own learning. TCs demonstrated good implementation of this criterion with two case studies scoring at an expert level and five at a practitioner level. The role of the teacher as a facilitator and the prevalence of student choice were evident in most case studies. For example:

> The teacher should circulate the room and support/observe group progress. Once all groups have completed their consequence maps, the teacher can facilitate a discussion where ideas from all groups can be consolidated. (Group A, lesson plan)

While most lessons followed a student-centered approach, some TCs chose direct instruction to introduce certain concepts or case study components such as the cost-benefit analysis and consequence maps. For example, Group C stated:

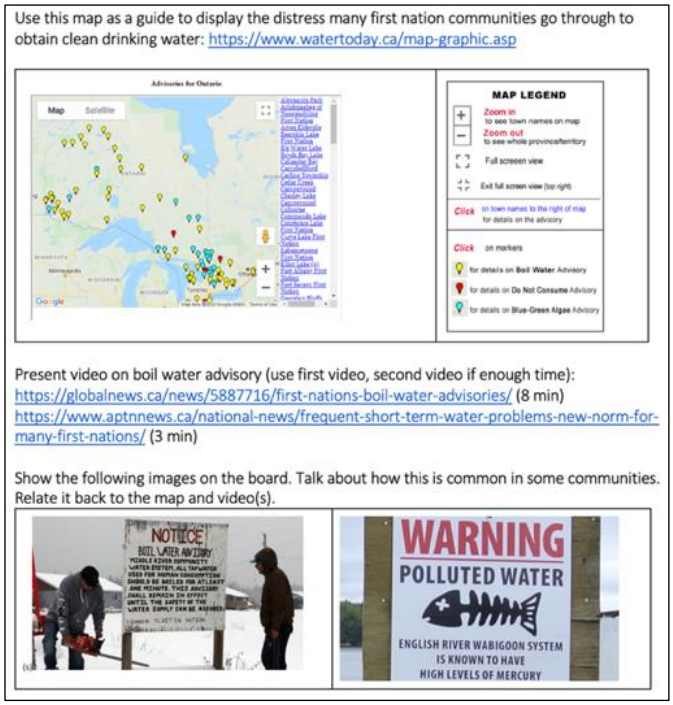
> Introduce students to consequence map and options for how to organize. Provide time for independent research and note taking using three methods. Provide time for group research for 'stakeholders' to amalgamate their research and formulate a stance. (Lesson plan)

Moreover, some TCs' excessive reliance on showing videos to explain certain concepts posed a few challenges in terms of the level of inquiry and student agency in the classroom. While videos and other audio-visuals are engaging, they may situate students as passive recipients of knowledge. Accordingly, TCs were advised to substitute those with other activities that enable students to lead and understand the content on their own. Furthermore, some TCs showed hesitation when providing students will full autonomy. This hesitation is expected from novice teachers who may not have the confidence to provide this agency to their students. For example, Group G stated: "Students will be assigned a stakeholder- they can also choose depending on class dynamics." (Lesson plan)

For the seventh criterion – technology integration – to attain the expert level, the case study should exhibit exemplary and proficient use of digital material. This action would render the lesson fully implementable in an online environment. TCs showed a good implementation of this criterion, with one case study scored at an expert level and six at a practitioner level. TCs included a vast array of digital resources such as Kahoot activities, simulations, digital maps, digital games, online articles, internet research, and audio-visuals. See Figure 2 for an example.

Figure 2

Sample Digital Activities, Group C – Water in Indigenous Communities, Supplementary Teaching Resources



Since the data was collected during the COVID-19 pandemic, TCs took into consideration the fact that they may use these case studies either in-person or in an online teaching environment and succeeded in this adaptation. Several groups were advised to maintain consistency in integrating digital resources throughout the case study lessons, and not only in some of them.

Domain 4: Student Assessment

For the first criterion, formative assessment, to attain the expert level TCs should plan to regularly use formative assessments throughout the lessons. Information from these lessons should be utilized in modifying instruction within a lesson, gauging student understanding, and planning future instruction for individuals and groups. TCs showed a very good implementation of this criterion with four case studies scored at an expert level and three at a practitioner level. TCs integrated formative, diagnostic, and summative assessments in their case studies. Several case studies explicitly included assessment for, of, and as learning within the lesson plans. Moreover, multiple tools were included to assess students such as a prior knowledge check, KWL charts, polling, lab sheets, fact sheets, worksheets, note-taking, exit tickets, student reflections, and rubrics for class discussions and debates. TCs' awareness of the importance of a variety of assessment strategies, especially formative assessments, is highlighted in the following excerpts from the lesson plans:

> Ensure that students come prepared with research notes taken from previous classes. Please review the following teacher instructions for Day 1 and Day 2 of the activity and read the student task to all students at the beginning of class. (Group C, lesson plan)

> Constant check-ins with the class to see if we are moving too fast or if they understand concepts. (Group D, lesson plan)

Furthermore, TCs provided students multiple ways to present their understanding, especially at the end of the case study. This strategy offers students multiple options to express and convey their understanding in ways that match their levels of readiness and interest. Major points of improvement in this criterion include: 1) integrating more variety in the assessment methods throughout the case study rather than relying only on the case study note-taking sheets; and 2) making the assessment section more explicit in the lesson plan, and not only in the lesson closure section, to highlight its importance and to reinforce the importance of ongoing assessment during the lesson rather than only at the end.

To attain the expert level on the second criterion, assessment rubrics and guidelines, TCs should clearly articulate the rubrics and guidelines through specific assessment criteria and standards. Students should have the ability to participate in the creation of the rubric/guidelines and actively plan next steps for learning. TCs showed a good implementation of this criterion with five case studies scored at an expert level and two at an apprentice level. Most case studies included clear and comprehensive rubrics for different instructional activities, especially the consolidating debate. Rubrics entailed clear indicators and specifications that measure various components such as students' knowledge, application, thinking, and communication. Two case studies at the apprentice level included assessment criteria such as worksheets but did not include rubrics for the final class discussion/debate.

Domain 5: Supportive and Inclusive Learning Environments

For the first criterion, EDI principles, to attain the expert level TCs must demonstrate a sophisticated understanding of EDI principles. They need to effectively implement inclusive and culturally responsive pedagogy. Planned lessons should fully reflect and attend to diversity (race, ethnicity, culture, religion, SES, immigration status, Indigenous communities, Indigenous histories and ways of knowing, sexual orientation, gender identity, etc.). TCs demonstrated good implementation of this criterion with three case studies ranked at an expert level, three at a practitioner level, and one at an apprentice level. First, the nature and choice of the case study topics around SSI made it easier

for TCs to relate their cases to EDI principles. For example, Group C tackled water filtration in Indigenous reserves, which directly relates to equity practices and Indigenous communities. Similarly, Group A discussed equity in accessing COVID-19 vaccines. Second, the case study format allows for addressing various backgrounds and perspectives. Student awareness of different perspectives on scientific topics could eventually lead to a more inclusive and respectful approach when discussing those topics, as illustrated in Table 2 in which the key stakeholders pertaining to each case study are included.

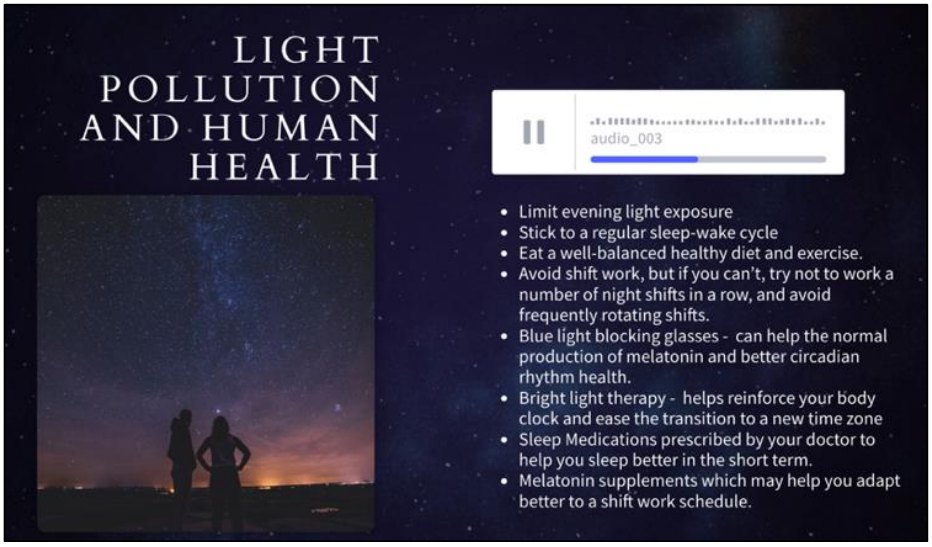
Moreover, TCs were aware of non-Western centric approaches in science. Many of them integrated Indigenous ways of knowledge within their teaching, as shown in the excerpt below.

> While vaccines are largely a product of modern and "Western" science, teachers should take care not to ignore or undermine other ways of knowing such as Indigenous ways of knowing. In the case of the prevention and treatment of communicable diseases, Indigenous science, and contributions to the development of medical treatments and remedies should be included in discussion... Care and consideration should be taken as Indigenous communities have historically experienced viral epidemics…. It is possible students in the class may have ancestors that experienced these epidemics... Below are some resources that can support both teacher's and student's understanding of Indigenous people, viral epidemics, and vaccines … (Group A, lesson plan and supplementary teaching resources)

Third, most TCs dedicated a part of their lesson plans to explicitly discuss EDI-related principles and teaching methods. TCs highlighted how they would address different student backgrounds and differentiate their instruction. For example, Group F planned for engaging parents as per Ontario's Equity Plan, providing accommodations and multimodal presentations, and addressing different backgrounds and perspectives. Group G included multimodal presentations, addressing different backgrounds and perspectives, and integrating Indigenous ways of knowledge. This finding shows that TCs were able to link DI to EDI principles. Finally, some TCs provided accessibility accommodations for students with different needs (e.g., visually impaired, ELLs, low reading proficiency) as shown in Figure 3.

Figure 3

Voice-over Option Provided by Group E as an Accommodation Strategy



For the second criterion, respectful behavior toward and among students, to attain the expert level the case study should foster active participation and questions from all students. Awareness of students' strengths, successes, and contributions are to be cultivated and celebrated. TCs demonstrated exemplary implementation of this criterion with six case studies ranked at an expert level and one at a practitioner level. For instance, TCs situated their roles as facilitators in the classroom, thus respecting student choices and discussions. On the other hand, Group C stressed respectful behavior among students in their instructions and assessment guidelines.

For the third criterion, sense of community and collaboration, to attain the expert level, the case study should enable students and teacher to consistently focus on both individual and group excellence and growth. Students should consistently engage and support one another in learning and be supported to work with any student in the class. TCs showed very good implementation of this criterion, with five case studies at an expert level and two at a practitioner level.

Domain 6: Evidence of Differentiation

The first criterion, content differentiation, refers to adapting what is taught and modifying how students are given access to the information and understandings (Tomlinson, 2001). The planned lessons need to be highly concept-based and make use of diverse materials at various levels of readability, complexity, and/or interest. Lessons shall include, but are not limited to, one or more of the following strategies: multiple ways to access and organize information, learning contracts, curriculum compacting, flex-group mini-lessons, and varied support systems such as audio/video recorders, note-taking organizers, highlighted print materials, digests of key ideas, and peer/adult mentors. TCs showed a novice implementation of this criterion with no case studies scored at an expert level, while five were scored at a practitioner level, and two at an apprentice level. As explained previously, TCs effectively utilized the different note-taking organizers as instructed by the course instructor such as KWL charts, Cornell's note-taking sheet, and consequence map. Yet, the lesson plans of most TCs did not adeptly change the complexity levels and/or the pace of learning for various students. This shortcoming justifies the relatively lower scores on this criterion compared to others.

The second criterion, process differentiation, refers to the instructional activities that represent a diversity of approaches at varying degrees of sophistication, with several levels of scaffolding, and completed in different time spans (Tomlinson, 2001). Process differentiation can happen in one or more of the following ways: readiness by matching complexity of task to student's current level of understanding; interest by giving students choices and linking to personal interests and/or goals; and learning profile by making sense of ideas reflected in the students' preferred way of learning. TCs demonstrated good implementation of this criterion, with three case studies rated at an expert level, three at a practitioner level, and one at an apprentice level. In addition to the previously included samples, the following samples reiterate the findings:

> This lesson includes multimodal representations of information (text, videos with audio, visual diagrams/descriptions etc.) ... The consequence map activity encourages inclusion of all student voices in group work and allows students to organize and express their thinking in a way which is not heavily reliant on writing skills. (Group A, lesson plan)

> For the research and Cornell note-taking activities, both videos and text-based learning is offered, in addition to oral discussion. Also, the arguments made during the debate do not need to strictly be verbal. Share text, images, and short videos if they can assist a student in making their point. (Group F, lesson plan)

The third criterion, product differentiation, refers to providing several product options that are designed to foster deeper and richer understandings of the unit's goals. Products may differ due to curriculum requirements or student readiness, interest, or learning profile (Tomlinson, 2001). Guidelines provide the perfect balance between structure needed to focus and guide students, and the freedom to support innovation and thought. Students collaborate with the teacher to design the project requirements, timeline for completion, and assessment criteria. The teacher works as a coach to facilitate, scaffold, and expand the students' thinking through flexible study groups, mini-lessons, and conferencing. TCs showed good implementation of this criterion with three case studies scoring an expert level, two at a practitioner level, and two at an apprentice level. Several groups provided a wide array of different assessment strategies for students to demonstrate their understanding. Nevertheless, additional options would provide more choice for students. TCs stated:

> Several opportunities to individualize and differentiate the assessment are available:
> - No more than two debates per day to give each student time to meaningfully participate. Following the debate, students will complete a cost benefit analysis of the Three Gorges Dam issue, along with the learned section of the KWL chart.
> - Brainstorm, discuss, then present (mind map, infographic, skit, etc.) different ways how technologies have made a change with our energy consumption. (Group F, lesson plan)

> - Students have the chance to communicate orally and in writing.
> - Digital, Differentiated Instruction - In lieu of writing a paper, teachers can also consider presenting students with the option of presenting their discussion and analysis in a pre-recorded video.
> - Students can then use visual graphics to support their arguments. This method may also remove some essay-writing anxiety. (Group G, lesson plan)

Quantifying Case Studies' Analysis

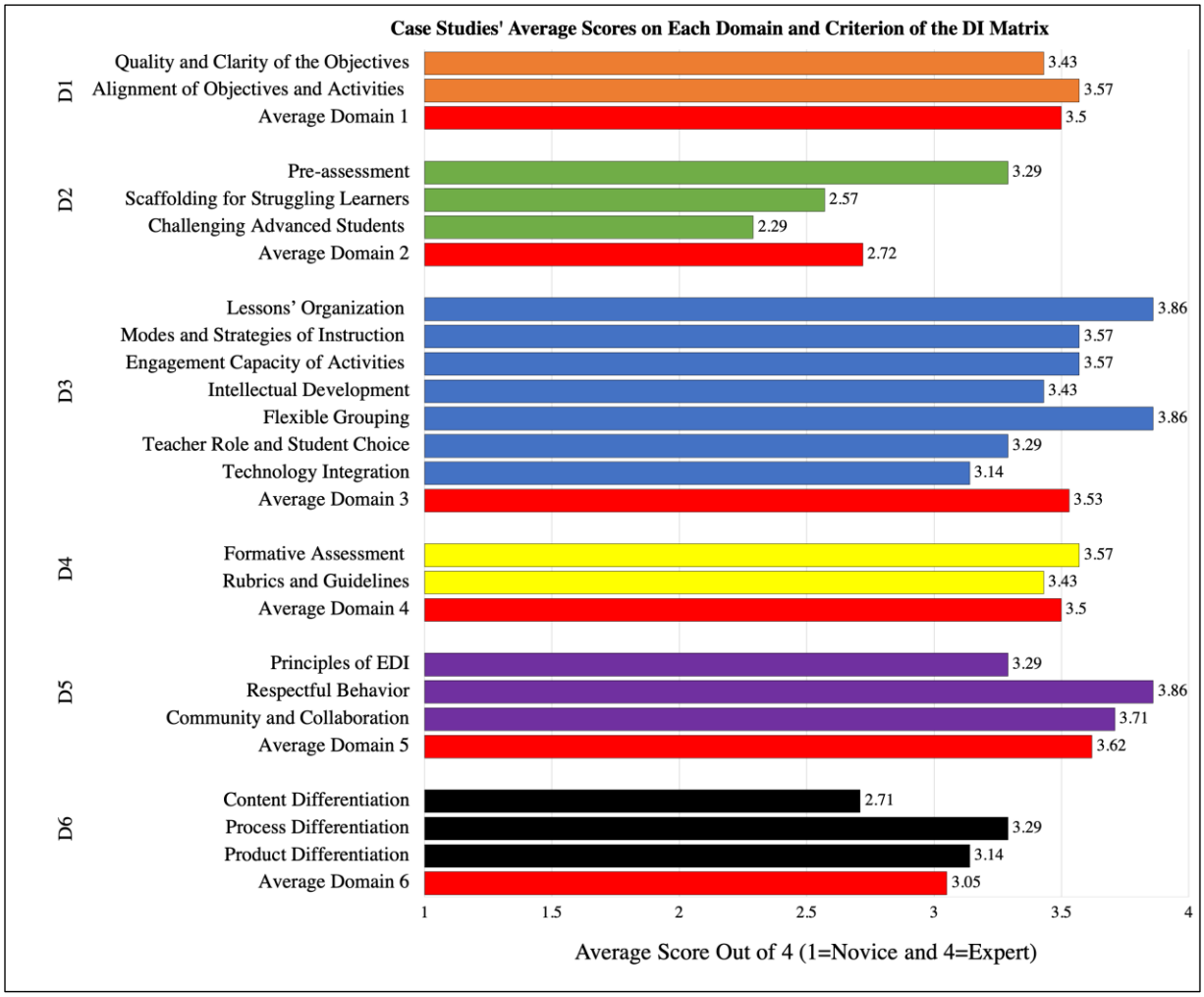
A score out of four was allocated to each case study in each of the 20 criteria in the DI Matrix, where (1) indicates "Novice", (2) indicates "Apprentice", (3) indicates "Practitioner", and (4) indicates "Expert". Figure 4 highlights the average scores of the seven case studies on each of the 20 criteria. In general, the average score on each criterion shows that the DI seminar and subsequent training had a positive impact on TCs' conceptions and implementation of DI. The average score of TCs' case studies between 1 and 2 was not recorded on any of the criteria, between 2 and 3 was recorded on three of the 20 criteria, and between 3 and 4 on 17 of the 20 criteria. This result shows that TCs showed practitioner to expert level on most criteria, which reflects good understanding and implementation of DI in the case studies. The highest scores were recorded on aligning the objectives with the activities (3.57), lesson organization (3.86), modes and strategies of instruction (3.57), engagement capacity of activities (3.57), flexible grouping (3.86), formative assessment (3.57), encouraging respectful behavior (3.86), and ensuring a sense of community and collaboration (3.71). These criteria scored between 3.5 and 4 which reflects an expert level.

On the other hand, other indicators reflecting a score between 3 and 3.5 show very good performance indicative of a practitioner level. These are quality and clarity of the objectives (3.43), pre-assessment and proactive preparation (3.29), working on students' intellectual development by addressing different thinking levels as per Bloom's taxonomy (3.43), teacher's planned role, learner independence, and student choice (3.29), technology integration (3.14), using rubrics and assessment guidelines (3.43), integrating the principles of EDI (3.29), differentiating the process (3.29), and differentiating the product (3.14). The three indicators that need improvement, indicative of apprenticeship level, are scaffolding for struggling learners (2.57) with four case studies showing

apprenticeship level, challenging advanced students (2.29) with five case studies showing apprenticeship level, and differentiating the content (2.71) with two case studies showing apprenticeship level, five case studies showing practitioner level, and none of the case studies showing expertise level.

Figure 4

The Average Score (out of 4) of the Seven Case Studies Per Domain (D1-D6) and Constituent Criteria



To obtain a general and holistic overview of TCs' implementation of DI in their case studies, the average score on each domain was calculated for all case studies by calculating the average score of the criteria in each domain (also shown in Figure 4). Additionally, the average scores on each domain were converted to percentages. TCs demonstrated exemplary performance on four of the six domains: Domain 1 – quality curriculum and lesson design (7 out of 8: 87.5%); Domain 3 – planned instructional practices (24.71 out of 28: 88.25%); Domain 4 – student assessment (7 out of 8: 87.5%); and Domain 5 – positive, supportive, and inclusive learning environment (10.86 out of 12: 90.5%). On the other hand, the averages on Domain 6 – evidence of differentiation was 9.14 out of 12 or 76.16%; Domain 2 – response to learner needs scored the lowest average of 8.14 out of 12 or 67.83%. The relatively low scores on Domain 2 are further reinforced on the content differentiation component in Domain

6. TCs showed relatively low implementation in terms of adapting the lessons to various academic achievement levels.

Discussion and Conclusion

Based on the findings, TCs were successful to a high extent in developing differentiated curriculum using the case studies of SSI. TCs showed excellent performance on four of the six domains: quality curriculum and lesson design, planned instructional practices, student assessment, and positive, supportive, and inclusive learning environments. However, the domains related to responding to learner needs and content differentiation showed relatively low levels. TCs demonstrated proficient integration of strategies related to differentiating the process most, followed by the product of learning yet showing a need for more training in content differentiation to attend to students' needs, backgrounds, and academic levels.

In terms of TCs' detailed DI skills, the relatively high scores on the assessment domain in the DI Matrix contradicts what is documented in the literature related to teachers facing difficulties in differentiating their assessment strategies (Rollins, 2010; Wan, 2017). However, a major area of improvement that this study highlighted is TCs' ability to differentiate the content component. TCs needed more guidance on how to scaffold learning for struggling students, attend to special need students, cater their teaching for various linguistic abilities, and challenge advanced students. This finding parallels the conclusion documented in other studies that teachers usually understand the differentiation of the content the least compared to other components (Estaiteyeh & DeCoito, 2023a, 2024; Turner & Solis, 2017). This finding is also in harmony with de Jager (2017) who maintained that most teachers find it difficult to adopt a flexible curriculum and provide extra time for their students. This challenge has also been documented by Wan (2017) who maintains that teachers believe that the great diversity among students in the same classroom poses difficulty in their ability to attend to all learner needs. Furthermore, it is important to note that while this analysis focuses on the ability of TCs to integrate DI strategies in their curriculum, DI was not the only focus of this assignment. For instance, this was the first experience for TCs developing case studies of SSI in the teacher education program despite their prior knowledge of case studies and SSI as stand-alone concepts/strategies. Thus, TCs had to address several criteria which may have hindered their full incorporation of DI.

TCs' work on DI-focused case studies also addresses two major challenges that typically hinder teachers' implementation of DI in their classes, i.e., limited curriculum resources and insufficient training (de Jager, 2017; Turner & Solis, 2017; Wan, 2017). Concurrently, this research addresses some of the pedagogical challenges that teachers face when teaching using case studies of SSI, including unfamiliarity with the strategy and difficulty matching case problems to course content (Mostert, 2007); tackling controversial issues and considering students' backgrounds (Şen Akbulut & Hill, 2020); self-efficacy beliefs to integrate SSI into the curriculum (Sibic & Topcu, 2020); availability of teaching resources (Hancock et al., 2019); and lack of training (Chang & Park, 2020).

In terms of the compatibility of case studies of SSI and DI, the overall analyses of the assignment design and requirements as well as TCs' coursework indicate that case studies of SSI are well suited to incorporate DI. This compatibility renders case studies of SSI as promising tools to differentiate instruction in STEM classrooms. This is mainly because case studies present multiple perspectives and opposing arguments on debatable topics (Hemphill et al., 2015) and enable multiple levels of analysis and interpretation (Levin, 1995), which is in accordance with the philosophy behind DI as an equitable and inclusive pedagogy in diverse classrooms (Estaiteyeh & DeCoito, 2023b; Tomlinson, 2021, 2022). Hughes (2000) maintains that SSI promote students' socioscientific awareness of the various dimensions to science and presents science as accessible to various underprivileged groups. Furthermore, since SSI advances students' reflective judgement and argumentation (Sadler & Zeidler, 2004; Zeidler et al., 2009), this assignment proved to be adequate for differentiating instruction, as

exemplified in TCs' coursework. This result was specifically facilitated by several components of the SSI case studies such as: 1) multiple stakeholders involved; 2) several sequenced lessons enabling the use of variety of teaching and assessment strategies; 3) multiple graphic organizers, note-taking frameworks, and sheets required in the analysis of the case; 4) presenting to different audiences; and 5) the debatable SSI topics that require attending to the rights and living conditions of minorities and underprivileged communities. Teachers can therefore capitalize on these components to embed DI practices within case studies of SSI, and thereby attain potential positive outcomes of both.

Limitations and Implications

One of the study limitations is the potential disconnect between TCs' curriculum development work and their classroom instruction. Due to the COVID-19 pandemic and the scope of the study, the researchers were not able to observe TCs while implementing their case studies in a classroom setting. As such, future research for teacher educators and researchers in the field can follow-up with TCs or in-service teachers on the implementation of case studies in their classes to attain the full picture of the impact, real-life successes, and challenges of the developed DI-focused curriculum. Additionally, given that the instructor provided TCs with feedback that guided their work, future research can explore the various levels of support and scaffolding that need to be provided to TCs so that they can engage in curriculum development proficiently. Moreover, further research for educators and curriculum designers can focus on how to develop strategies related to content differentiation specifically, which was noted as a significant challenge for TCs in this study.

This research advances knowledge about DI as a pedagogical practice in STEM education utilizing case studies of SSI. This is a unique study that presents case studies of SSI as an avenue to facilitate DI. STEM TCs in this study were provided with rich opportunities to engage with DI as a form of professional development. The explicit, reflective, collaborative, and interdisciplinary training model, showcased in this study, is of benefit to STEM teacher education programs. Adopting this training approach addresses significant gaps in the literature and the practice related to integrating equitable and inclusive pedagogies in STEM curriculum as well as creating teaching materials relevant to case studies of SSI. Overall, this work offers a foundation for a multi-year effort, providing important data for STEM researchers regarding 1) prior preparation needed by TCs as an entry point to this field; 2) multiple experiences that may enable TCs to navigate this complex landscape in meaningful ways; and 3) various classroom-based and/or online experiences that may enable TCs to experience how the theory plays out in actual classroom contexts.

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