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Technology-Enhanced Differentiated Instruction in STEM Education: Teacher Candidates' Development and Curation of Learning Resources

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This research explored how teacher candidates (TCs) developed and curated learning resources that are both digitally enriched and focused on differentiated instruction (DI). The authors present the analysis of a course assignment in which TCs developed multimedia curriculum resource websites suitable for use by secondary teachers of science, technology, engineering, and mathematics (STEM). The research addressed the following research question: What examples of technology-enhanced DI do TCs incorporate in their curriculum resource websites? The analysis of 18 websites shows how TCs incorporated digital learning resources to promote DI principles and practices in their lesson plans. Implications for STEM education research and practice are discussed.

Due to increased diversity among students, schools in Canada are prioritizing equity, diversity, and inclusion (EDI) policies (Ontario Ministry of Education, 2017). Teachers strive to implement practices that consider students' backgrounds, interests, and academic achievement levels. Pedagogically, differentiated instruction (DI) is an equitable and inclusive teaching philosophy that can address student differences (Specht & Metsala, 2018; Tomlinson, 2001). Yet, the literature on DI in science, technology, engineering, and mathematics (STEM) subjects documents the need for better teacher training and preparation (de Graaf et al., 2019; Maeng & Bell, 2015). This warrants a focus on teacher candidates' (TCs') knowledge base in preparation for teaching in classrooms reflecting heterogeneous student populations.

Despite the rapid developments in educational technologies, teachers' use of digital tools in practice is limited. DeCoito and Richardson (2018) investigated the use of technology by middle school teachers in Canada and noted a disconnect between their beliefs and practice. Teachers believed technology is important but reported utilizing it for administrative and presentation purposes. The researchers noted that teachers integrate technology for low-level tasks more than high-level tasks. They categorized factors influencing teachers' use of technology as both external (such as availability of resources, training, and support) and internal (such as personal investment in technology, attitude toward technology, and peer support).

Hughes et al. (2020) noted that TCs are more experienced in presentational technologies and in teacher-focused rather than student-focused techno-activities. They recommended better preparation of TCs through engagement with content-focused techno-activities and pedagogical reasoning related to educational technology use. Similarly, Ng (2013) echoed the recommendation of better teacher preparation to harness the potential of educational technologies.

Thus, continuous professional development is essential to enhancing teachers' and TCs' technological, pedagogical, and content knowledge (TPACK) and, thereby, advancing their proficiency levels in integrating technology in their practices (Asim et al., 2022; Aulpaijidkul et al., 2022; Graziano et al., 2023; Wang et al., 2018).

With respect to EDI practices, the integration of technology with DI in secondary classes is promising despite limited and inconclusive research (Estaiteyeh & DeCoito, 2023b; Maeng, 2017). Teachers believe that more is needed to maximize the use of technology to support DI (Cha & Ahn, 2020). Despite the intensified use of digital tools during the COVID-19 pandemic, a study of STEM teachers in Canada reported difficulties differentiating instruction in online settings (DeCoito & Estaiteyeh, 2022). Teachers' pedagogical challenges included a scarcity of digital learning resources aligned with curriculum. Thus, it is crucial to advance teachers' use of digital resources, while concurrently attending to student differences by integrating DI strategies.

In this study, we addressed teacher preparation on the inclusion of technology-enhanced DI. TCs were tasked with developing multimedia curriculum resource websites for use by secondary STEM teachers. The research explored how TCs created and curated learning resources that are both digitally enriched and DI-focused. Through the analysis of TCs' developed websites, the research examined the following research question: What examples of technology-enhanced DI do TCs incorporate in their curriculum resource websites?

Literature Review and Conceptual Framework

Differentiated Instruction

Employing best practices to meet individual student's needs, interests, backgrounds, and profiles is central to DI. In summary, DI is an approach in which teachers modify curricula, teaching methods, resources, learning activities, and student products to address their diverse needs and provide them with optimal learning (Tomlinson, 1999). Researchers consider DI a philosophy of teaching and not simply an instructional strategy (Coubergs et al., 2017), suggesting that DI is a proactive, flexible, and principle-based way of thinking about teaching and learning that meets student differences (Tomlinson & McTighe, 2006).

DI can occur through modifying the content (curriculum taught and resources), process (the way learning is structured and the learning environment), and product-assessment strategies (Tomlinson, 2001). This DI implementation model – the content, process, and product (CPP) – is used as a conceptual framework in this article. The CPP modifications are based on student readiness (academic achievement levels), interest or choice, and learning profiles, including their cultural backgrounds and lived experiences (Beasley & Beck, 2017; Tomlinson, 2014; Willis & Mann, 2000), as exemplified in the following list:

- Content differentiation addresses students' prior knowledge and conceptual understanding through flexible pacing, reorganization of concepts, curriculum compacting, and acceleration (De Jesus, 2012; Tomlinson & Imbeau, 2010).

- Process differentiation includes teaching methods such as cooperative learning, problem-based learning, tiered assignments, learning contracts, and flexible grouping and timing to differentiate the instruction (Goodnough, 2010; Tomlinson, 2014).

- Product differentiation allows students to share their learning in a variety of formats. Teachers can use rubrics that align with students' varied skills levels, with students working alone or in groups to develop products per the required specifications. As well, DI requires that teachers provide feedback and ongoing formative assessments to plan subsequent instructional activities (De Jesus, 2012; Levy, 2008; Wan, 2017; Watts-Taffe et al., 2012).

The literature documents the need for promoting preservice and in-service teachers' understanding and implementation of DI. For instance, Paone (2017) noted that teachers have positive perceptions of DI, but several challenges hinder its implementation, such as the lack of professional development, resources, and planning time. Adlam (2007) maintained that most teachers are familiar with DI strategies but are not confident in using them due to a lack of resources and knowledge of how to use DI tools.

Studies with preservice teachers and beginning teachers have also reported lack of confidence as a deterrent to DI implementation (Brevik et al., 2018; Casey & Gable, 2012). Dack et al. (2019) and Dee (2010) stressed the importance of supporting novice teachers in developing a practical vision of DI enactment in addition to a theoretical overview, hence, the focus in this research on TCs' exposure to DI strategies and development of digital learning resources that support these strategies.

Technology-Enhanced Differentiated Instruction

Information and communications technology (ICT) offers ways to support science learning and teaching, including Internet-supported research projects, games, simulations, modeling software, data-logging for data collection, text and multimedia-editing software, and collaborative online environments (Ng, 2013). Students can use simulations in making predictions, visualizing processes, organizing material, collecting data, and graphing data. They can also use computer-based modeling in identifying relevant variables, hypothesizing relationships, and developing understanding of the scientific ideas that they are modeling. Students can use various electronic solutions to communicate and discuss results, synthesize knowledge through digital stories, display concepts in multiple representations, and demonstrate their understanding (Derman & Ebenezer, 2020; Webb, 2005). These dynamic and malleable digital resources have the potential to support different learning needs (Hill & Hannafin, 2001).

Teachers can utilize technology when differentiating instruction in science classrooms (Boelens et al., 2018; Cha & Ahn, 2020; Estaiteyeh & DeCoito, 2023a; Heilbronner, 2013; Maeng, 2017). This can be accomplished through modifying instructional pace for students (Heilbronner, 2013; Karatza, 2019; Maeng, 2017); presenting content in various modes using multimedia, and by supporting students individually and in groups (Karatza, 2019; Scalise, 2009; Siegle, 2014); facilitating content creation (Colombo & Colombo, 2007; De Lay, 2010); and offering several avenues for students to express their understanding (Heilbronner, 2013; Karatza, 2019; Maeng, 2017).

In addition to assisting students with special needs (Olsen, 2007; Shepherd & Alpert, 2015), technology-enhanced DI outcomes include better student achievement in science (Haelermans et al., 2015; Zheng et al., 2014) and enhanced attitude toward learning (Collins, 2018). Due to the emerging nature of this research area and rapid advancements in technological solutions, teachers and TCs need training and pedagogical support in technology-enhanced DI (Boelens et al., 2018; Karatza, 2019; Millen & Gable, 2016).

Digital Learning Resources and DI

Digital learning resources are digital tools such as text, audio, images, photos, videos, simulations, animations, learning objects, Internet technology, software development technology, virtual reality technology, and artificial intelligence technology that are incorporated in a curriculum and add significant value to the teaching and learning experience (Apoki et al., 2020).

The National Academies of Sciences, Engineering, and Medicine (2021) maintain that high-quality science instruction requires learning resources that are grounded in investigation and design; are coherent, flexible, adaptable, equitable, and responsive; and have evidence supporting their effectiveness. They noted that learning resources are not readily available to teachers. Margaryan and Littlejohn (2008) maintained that digital learning materials are often designed to exploit the capabilities of technology rather than to meet learners' needs. Similarly, Peruzzo and Allan (2022) call for rethinking digital education to counteract the digital divide exacerbated by the COVID-19 pandemic. Peruzzo and Allan recommended an inclusive design framework that recognizes learners' diversity when using digital pedagogies.

Lack of curriculum resources is one of the most common challenges for teachers to differentiate their instruction (Turner & Solis, 2017; Wan, 2017). Therefore, it is important to explore how digital learning resources can reflect EDI principles and integrate DI strategies. The literature also recommends that teachers be more involved in the processes of improving inclusive curricula and materials (Tomlinson et al., 2003). It is also essential to ensure that TCs and teachers are equipped with these resources, involved in developing them, and introduced to their pedagogical use to facilitate future teaching of students with diverse needs (Camilleri & Camilleri, 2017).

Despite limited research on obtaining and developing inclusive digital learning resources, a few examples in various disciplines are documented. In terms of cultural diversity, Jaramillo Cherrez and Gleason (2022) explored TCs' development of intercultural awareness using digital tools in a virtual exchange experience. Similarly, Fierros and Foley (2005) examined how digital technologies can be used to promote TCs' cultural awareness and integrate culturally responsive teaching in their practice.

Second, for linguistically diverse classes Siefert et al. (2019) examined how digital technology was used to create rich and varied learning opportunities for English learners, emphasizing the importance of teacher training and equitable learning opportunities for English language learners (ELLs).

A third aspect of inclusive digital learning resources pertains to students with special educational needs (Alves et al., 2015; DeCoito & Briona, 2020; Hanghøj et al., 2018; Malinverni et al., 2017; Salgarayeva et al., 2021). For example, Du and Lyublinskaya (2022) explored the potential of assistive technology combined with inquiry-based teaching to support inclusion of students with diverse learning needs.

Finally, a fourth aspect of EDI application of digital resources is the integration of DI within said resources. For example, Wu et al. (2019) explored a virtual reality chemistry lab combined with DI to increase confidence of students with different learning abilities. A few research studies explored how digital resources such as digital video games (DVGs) can address individual learning needs of students (Cheng et al., 2021;

Estaiteyeh & DeCoito, 2023a; Wang, 2017). Additionally, teachers can integrate multimodal teaching strategies to address students' needs (Grande & Whalen, 2017) and increase their engagement (Abouhashem et al., 2021). Multimodality is a distinctive feature in digital learning resources and is inherent in the curriculum resource assignment, the focus of this paper.

Method

Research Design and Participants

The study adopts a qualitative methodology approach (Creswell & Creswell, 2018). Participants included 18 TCs (eight males; 10 females) between 22 and 25 years of age, belonging to Asian (6), and White/Caucasian (12) ethnic groups. Teacher candidates' educational backgrounds included three master's degrees and 15 bachelor's degrees. Participants were enrolled in a Year-2 STEM education course in a teacher education program at a Canadian university. Upon program completion, TCs were certified to teach STEM subjects such as general sciences, biology, math, physics, chemistry, and health and physical education in grades 9, 10, 11, and/or 12.

Course Overview

The 12-week course was implemented online due to the COVID-19 pandemic, with 3-hour weekly meetings. In the first 2 weeks, the course instructor collaborated with the researcher to facilitate a workshop on DI and EDI in STEM education. In this workshop, TCs were exposed to theoretical principles and foundations of DI, Ontario's Equity Action Plan (Ontario Ministry of Education, 2017), Ontario's DI handbook (Ontario Ministry of Education, 2016), and practical strategies for implementing DI according to the CPP framework. TCs were also provided with readings and resources to assist them with understanding and implementing DI.

Afterwards, EDI principles and DI strategies were emphasized in all assignments, in-class tasks, and resources. TCs were requested to incorporate DI in their coursework and were provided feedback to ensure effective integration (Estaiteyeh & DeCoito, 2023b). Coursework included developing case studies of socioscientific issues, DVGs, and curriculum resource websites (DeCoito, 2023). These websites are the focus of this paper.

Curriculum Resource Assignment

In this task, TCs researched and developed multimodal curriculum resources websites suitable for use by grades 10, 11, or 12 STEM teachers. Each website addressed one unit/strand of the general science, biology, chemistry, or physics Ontario curriculum. The STEM curriculum resources showcased student-centered and inquiry-based pedagogical strategies, with an emphasis on digital resources. Each website was required to include 11 common sections, as exemplified by the following online content page: https://sites.google.com/view/stem-website-sbi3c/cellular-biology. TCs established active links to specific websites, images, and multimedia learning objects on the Internet, as well as related coursework developed by them or their peers in course assignments. TCs chose platforms to host their websites; 15 chose Google Sites and three chose Wix.com.

TCs were provided with instruction on building and curating digital resources, time in class to work on their resources, and feedback from the instructor and peers on their progress. TCs were assessed based on a final website product, two progress reports, and a reflection. The rubric addressed the following criteria: Information Accuracy and Appropriateness, Concept Development, Content Organization, Creative Piece, Principles of EDI (e.g., differentiating instruction, Indigenous ways of knowing, etc.), Text (writing style, spelling, grammar, etc.), Graphics, Creativity and Originality, and References. Including EDI principles and DI strategies within the assessment criteria made this requirement explicit and reinforced that these principles are applicable across all assignments.

Data Sources and Analysis

The data for the study included the 18 curriculum resource websites developed by the TCs. The data set included all digital learning resources linked within the websites, the lesson plans developed by TCs, and detailed descriptions of adopted DI strategies the TCs incorporated.

Data analysis adopted a deductive approach (Creswell & Creswell, 2018), in which the CPP framework (Tomlinson, 2001) was utilized for the analysis of the websites. The *content, process, and product* differentiation constituted the predetermined themes for the analysis using the examples provided earlier (in the literature review section) as an initial list of codes under each theme. The websites were qualitatively analyzed to describe and explain the level of integration of different DI strategies.

First, a simple frequency count of website elements provided a general overview of the number of DI strategies adopted by each TC. Each DI link was then described and evaluated so the strategies incorporated could be tallied under the appropriate DI themes – content, process, and product. The websites developed by TCs were then scored as exemplary, proficient, or novice. Scores were assigned as follows: three and more DI strategies under each theme were categorized as exemplary; two DI strategies under each theme were considered proficient; none or one DI strategy under each theme were deemed novice.

The first author conducted the analysis, and the second author reviewed it, providing comments and corrections. The two authors discussed and finalized the ratings. This process of iterative and collaborative analysis combined with the detailed description of TCs' websites ensured the trustworthiness of the analysis (as suggested in Creswell & Creswell, 2018).

Results

DI in STEM Curriculum Resource Websites

TCs addressed DI principles in general in more than one section of their websites, such as the lesson plans, teaching strategies, assessment methods, societal implications, and foundations of professional practice. In all websites, TCs showed adequate to high inclusion of DI principles and strategies, utilizing a wide array of creative and engaging tools. TCs demonstrated differences in their understanding and proficiency when integrating DI in their resources, with some TCs showing a greater depth and variety in their DI-focused strategies. The appendix presents examples of this variation in DI incorporation.

Overall, TCs' work demonstrated that they were able to prepare lessons and compile a high number of digital learning resources while integrating a DI framework. The following sections describe examples of DI, especially technology-enhanced DI, TCs incorporated in their curriculum resource websites.

Differentiating the Content

TCs addressed content differentiation in various ways (see Table 1 for examples). First, they dedicated a section to common student misconceptions related to their science unit and researched specific strategies to address those misconceptions. In doing so, TCs acknowledged students' prior knowledge and expected levels of understanding and considered these data in their planning. TCs scaffolded learning by reviewing background knowledge, including real world connections to the content, and emphasizing conceptual understanding (see example of "all fats are bad" at https://sites.google.com/view/stem-website-sbi3c/cellular-biology/misconceptions).

Second, in the societal implications section, TCs explored how to include various topics related to EDI principles in their lessons. Most TCs linked their science topics to equity matters (see example of women in STEM at https://sites.google.com/view/stem-website-sbi3c/cellular-biology/societal-implication-and-applications), cultural differences, and social justice issues (see example of Indigenous communities at https://sites.google.com/view/stem-website-sbi3c/plants-in-the-natural-environment/societal-implication-and-applications).

Third, TCs attended to academic achievement levels of students. For instance, they planned to extend learning for high achievers through advanced activities and content. They offered equitable support to individual students who may lag in their readiness (such as hands-on support, additional reading options, extra help, additional resources, familiarizing ELLs with key-terms, and note sharing among students). This type of academic support can be seen in the lesson on the respiratory system at https://sites.google.com/view/stem-website-sbi3c/anatomy-of-mammals/lesson-sequence. In this example, the teacher assigned articles at different reading levels for students to select from and be able to conduct their research.

Table 1
Subject-Specific Examples of Content Differentiation

Unit, Subject, and Class	Content Differentiation
Sustainable Ecosystems-Science Grade 9	- Students are asked to explore and critically analyze articles on the disproportionate impact of climate change on developing countries, how wealthy consumption threatens species and habitats in developing countries, and relationship between environmental sustainability and poverty reduction.
Microbiology-Biology Grade 11	- In the creative piece, DVG, students can customize their characters and represent themselves, hence accommodating to students of many different nationalities and races. - Highlighted the differences in gut microbiome between people of different nations.
Gravitational Fields-Physics Grade 12	- Included resources that show non-Western contribution to science such as the views obtained from a Chinese-made spacecraft.
Anatomy of Mammals-Biology Grade 11	- Highlighted comparative anatomy and race science, addressing concepts such as unequal representations in media (healthy eating and body image), mental illness (effects of smoking on health and society), poverty (healthy eating and food choices), and Indigenous perspectives in science. - Incorporated students' interests into the lessons by including content related to pop culture (advertisement analysis), robotics (Ozobots), health and wellness (smoking), etc.
Energy Changes-Chemistry Grade 12	- The virtual calorimetry lab provides opportunities for those who cannot afford to conduct physical calorimetry experiments to experience calorimetry (in case students are learning at home).
Chemicals in consumer products- Science Grade 12	- One of the lessons on hazardous waste included a video about the dirtiest river in the world highlighting inequity, as the wealthier population in the surrounding regions are dumping their waste into that river while those that rely on the river for income are put at a huge disadvantage.

Fourth, TCs prepared the content in various forms, for example by having lab instructions delivered through auditory, audio-visual, and written text, and teacher demonstrations. Some TCs also indicated that students can access information they need to learn both electronically and on paper. In certain lessons, TCs offered two options for labs, in person and virtual, so that learning would not be limited by resources, attendance, or other circumstances (see virtual pig dissection activity at https://sites.google.com/view/stem-website-sbi3c/anatomy-of-mammals/teaching-strategies-ideas-resources).

Fifth, TCs provided students with agency in their learning by emphasizing choice and involving them in leading the learning goals of the day. Finally, varying lesson pace for different students was a common content differentiation strategy among TCs. This strategy provided students extra time to complete class activities, videos and worksheets ahead of time to review, and previously taught materials for the entirety of the course. Table 1 presents subject-specific examples of content differentiation planned by the TCs.

In terms of technology-enhanced strategies in content differentiation, TCs supported different reading abilities by using online dictionaries, translators, and speech-to-text apps for students with special needs and ELLs. The content was also prepared in various forms, for example, by having lab instructions delivered through both auditory and visual/written ways and different formats of the lesson (written documents, slides, and videos). Some TCs ensured that lessons utilized digital technologies such as Google Read and Write to allow students of all abilities to access learning.

Several TCs incorporated digital technology tools focusing on students' diverse backgrounds. For example, TCs included representation of different minority groups in digital materials through avatars in DVGs and characters in multimedia tools. Additionally, digital games and simulations were levelled to address different academic levels, whereby students can spend the time on specific concepts at their own pace before moving to more advanced topics.

Differentiating the Process

The inclusion of five lesson plans utilizing the curated digital learning resources in each website enabled TCs to utilize a wide variety of teaching strategies – an important feature in process differentiation. TCs included sections for numerous student-centered and creative teaching strategies, in addition to multimodal resources that are mostly digitally enriched. TCs attended to student differences in academic achievement levels, interests, cultural backgrounds, socio-economic status, linguistic abilities, and special needs (see sample lesson plans at https://sites.google.com/view/stem-website-sbi3c/plants-in-the-natural-environment/lesson-sequence).

In addition to planning independent activities, collaborative group work was emphasized, including flexible grouping, mixed ability/heterogenous grouping, homogenous grouping, rotating learning centers, class discussions, think-pair-share, alternating seating, and peer teaching and small groups to accommodate for ELLs and students who need more academic support.

Additionally, TCs incorporated active learning strategies such as jigsaws, carousel questions, hands-on labs, physical exercises, thinking classroom approach, problem solving, and class discussions to increase student engagement. TCs included videos, knowledge-based lectures, simulations, DVGs, debates, articles, case studies, experiments, hands-on activities, manipulatives (such as molecular model kits), inquiry-based activities, whiteboard games, and various other learning resources to promote student learning (see sample teaching resources section at https://sites.google.com/view/stem-website-sbi3c/cellular-biology/teaching-strategies-ideas-and-resources).

Student choice and autonomy were emphasized in TCs' lessons. For example, students may choose their own groups to share their learning, teach each other, and decide on activities or modalities of interest within the same lesson. One example in the Grade 12 “Chemicals in Consumer Products” unit was a lab activity in which students experiment with different household items to produce their own product inspired by their interests.

In terms of technology-enhanced strategies in process differentiation, TCs incorporated multimodal resources such as multimedia (memes, interactive animations, slides, pictures, infographics, songs, and videos) to cater to student interest and foster engagement. They also included a wide array of virtual tools, such as virtual labs, collaborative tools, DVGs, virtual dissections, and software, for drawing labelled diagrams and graphing.

In many instances, TCs offered two options for the same activity, such as a virtual simulation and a hands-on activity or wet labs and virtual labs through Gizmos. Sample teaching resource sections highlight how the range of digital learning resources used to promote student engagement and learning (such as the interactive application on plants at https://sites.google.com/view/stem-website-sbi3c/plants-in-the-natural-environment/teaching-strategies-ideas-resources and the virtual microscope at https://sites.google.com/view/stem-website-sbi3c/anatomy-of-mammals/teaching-strategies-ideas-resources). Many of these resources were curated using publicly available resources, and TCs included a brief description of the tools along with a pedagogical rationale for their inclusion. In other instances, TCs included digital learning resources and activities that were personally developed in the course, as shown in the example of the DVG on cell membrane at https://sites.google.com/view/stem-website-sbi3c/cellular-biology/creative-piece-dvgs.

Differentiating the Product

In product differentiation, TCs integrated various assessment types *for* learning, *as* learning, and *of* learning (diagnostic, formative, and summative assessments), as shown in the sample at https://sites.google.com/view/stem-website-sbi3c/cellular-biology/assessment. TCs included diagnostic quizzes to check prior knowledge and for students to gauge their strengths and weakness. Most TCs included rubrics that emphasized specific learning objectives and outcomes, especially for summative assessments. Additionally, TCs planned multiple assessment strategies, such as lab reports, debates, literacy questions, worksheets for simulations, exit tickets, infographics, building models, and graphic organizers (e.g., placemat, compare contrast, etc.).

TCs planned differentiated assessments by considering students’ readiness and learning profiles. For example, TCs developed resources with increasing difficulty and variation in types of question (knowledge based, application, and analysis). Open-ended assessments provided students freedom of choice in relation to the required deliverables/products according to their preference and interest (e.g., oral presentations, posters, videos, papers, etc.). For example, student options for conveying their understanding of organelle function included a rap song, poem, skit, poster, or graphic organizer (as shown at https://sites.google.com/view/stem-website-sbi3c/anatomy-of-mammals/assessment). Other options included handwritten or typed lab reports and cocreating rubrics and success criteria with students.

Technology-enhanced strategies in product differentiation included virtual options for assessments, such as Mentimeter, Plickers, Quizlet, Socrative, Kahoot, and Quizizz, in which TCs incorporated interactive virtual exit tickets, diagnostic assessments, and formative assessments. TCs relied on virtual tools (e.g., PearDeck, Padlet, Google Forms, etc.) to collect students' reflections and conduct self-checks. One TC developed a "virtual four corners" activity, in which students reflect on their understanding and are directed to subsequent review activities based on their academic levels. Several digital learning resources incorporated response systems, in which students receive instant feedback before moving to the next level or concept.

Discussion and Conclusion

This paper describes our examination of STEM TCs' development of digital curriculum resources focusing on DI. The analysis of websites focused on the level of incorporation of differentiation (exemplary, proficient, and novice) according to the CPP framework (Tomlinson, 2001). Findings reveal that TCs demonstrated varying abilities in terms of incorporating DI practices (see appendix), with most TCs showcasing proficiency in differentiating the process and product components. However, the TCs were less successful incorporating differentiated instruction in the content component. This finding aligns with the literature documenting challenges teachers typically face with content differentiation (Turner & Solis, 2017).

With content differentiation, it was evident that TCs addressed student misconceptions, emphasized conceptual understanding, and developed culturally relevant content. They addressed varying academic achievement levels in the same lesson with a variety of strategies, such as supporting individual students, providing content in various forms and modalities, and offering students with agency and choice.

TCs' websites indicated their intention to utilize ICT to support students' differences. For example, TCs included digital tools such as DVGs, simulations, virtual labs, and animations with varied levels of difficulty. TCs included auditory, audiovisual, and written instructions to support different reading abilities. As well, links to online dictionaries, translators, and speech-to-text apps for students with special needs and ELLs were provided.

TCs planned varied lesson pacing for students with varying abilities through additional time to complete class activities and additional resources. The accompanying scaffolding and multiple means of representation, evident in the websites, explicitly addressed DI principles, especially the content component (consistent with Tomlinson et al., 2013). Our findings inform the literature on the potential of new technologies to tackle content differentiation by modifying the instructional pace, thus allocating time for teachers to work with gifted or struggling students (Heilbronner, 2013; Karatza, 2019; Maeng, 2017). Moreover, planning resources in ways that cater to student interest and background combined with utilizing a STEM framework aligns with Milman et al.'s (2014) assertion that technology can offer various choices of the same content for students to engage with and integrate content from various subjects in an interdisciplinary approach.

In terms of process differentiation, TCs attended to student differences in academic readiness, interests, linguistic abilities, and special needs (as outlined in Ontario Ministry of Education, 2013). TCs included various active and collaborative learning strategies, including mixed ability group work, learning centers, class discussions, active learning strategies, case studies, manipulatives, and inquiry-based activities. Digital resources focused on students' readiness and interests, and the array of simulations and animations addressing different levels of conceptual understanding align, with research findings highlighting the importance of technology in process differentiation (Colombo & Colombo, 2007; De Lay, 2010; Karatza, 2019; Scalise, 2009; Zheng et al., 2014).

In product differentiation, TCs integrated assessment *for* learning, *as* learning, and *of* learning— diagnostic, formative, and summative assessments (Drake, 2014) and incorporated multiple assessment strategies by considering students' readiness and learning profiles. These included lab reports, debates, worksheets, exit tickets, infographics, building models, graphic organizers, and multimodal products reflecting student choice (oral presentations, posters, videos, papers, etc.). Digital assessment resources in this study showcased how technology can maintain ongoing, flexible, and interactive forms of assessment (as described by Heilbronner, 2013; Karatza, 2019; Kassissieh & Tillinghast, 2014; Maeng, 2017). Furthermore, TCs' ability to plan differentiated assessments addresses a major gap in teachers' practice as reported in the literature (Griful-Freixenet et al., 2021; Kendrick-Weikle, 2015). Griful-Freixenet et al. indicated that the ongoing assessment construct is the most important predictor for DI and other inclusive pedagogical practices. Hence, based on our findings, we recommend that TCs develop proficiency in the design of different types of assessments that should be modeled in teacher education programs.

TCs' ability to integrate DI in this assignment was facilitated by (a) ongoing feedback they received, (b) collaboration that further advanced their expertise in DI-focused learning resources, (c) explicit DI training at the beginning of the course and throughout all course tasks and assignments, and (d) digital learning resources and the assignment, which afforded DI integration to a greater extent (Estaiteyeh & DeCoito, 2023c). It is noteworthy that this assignment was a culminating task in which TCs compiled a wide collection of STEM learning resources focused on DI strategies. Nevertheless, TCs' ability to design DI-focused resources affirms the need to support TCs across disciplines to integrate EDI principles and DI practices in teacher education programs (as also recommended in Dack, 2018; Dee, 2010).

Implications, Limitations, and Future Research

Differentiated instruction is central to equitable and inclusive education. Resource availability poses a significant challenge to DI implementation (Adlam, 2007; Griful-Freixenet et al., 2021). This study highlighted the creation of a repository of digital learning resources focused on DI. The context is unique to a STEM specialty program in teacher education. The approach addressed a gap in the literature and can inform STEM teachers, teacher educators, STEM education researchers, and curriculum designers as to the affordances and challenges teachers face in the classroom when considering resources for DI implementation. Findings can inform professional development initiatives, focusing on strategies for integrating technology and DI principles in practice.

One limitation of this research is the use of the DI-focused digital resources in practice, warranting future explorations of TCs' implementation of these resources. Finally, future research can focus on developing learning resources that address content differentiation specifically, which was noted as a necessary area for improvement in TCs' work.

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Appendix

Samples of TCs' STEM Curriculum Resources Websites Showcasing Varied Levels of DI

Level	Content Differentiation	Process Differentiation	Product Differentiation
Exemplary	• Culturally relevant content, e.g., how diets are influenced by culture and SES • Extending learning through a group research activity about the four macromolecules • Discussed how equity affects health (diabetes in urbanized areas) • Research about the historical discoveries: contributions of scientists of colour and women • Familiarized ELLs with key-terms before the start of content explanation	• Included variety of active, student-centered teaching strategies: simulations about diffusion, case studies, biochemistry memes, hands-on building macromolecules, etc. • Included learning through multimodalities: videos, songs, discussion, graphic organizers, pictures, etc. • Student choice in activities • Planned independent thinking activities (e.g., KWL charts) and group work (e.g., discussions or group activities)	• Different forms of assessments for students: provided through a list of suggestions, with other ideas are open to consideration. For example, options to present research on organelle function include a rap, poem, song, skit, poster, graphic organizer... • Included in the lesson plans varied forms of assessment *for* learning, assessment *as* learning, and assessment *of* learning • Rubrics included within each lesson
Proficient	• The plant adaptations lesson plan included biomes from across the globe • Included a lesson where students research different Indigenous communities and their contributions to ecosystem sustainability	• Included visuals, videos, tables, infographics, apps, charts, labs, and hands-on activities • Gave students choice on how they would like to organize their research for example, mind map, table chart, list, etc.	• Assessments provide students with choices and autonomy: Students can choose the format of delivery of their work. Planned a few assessment strategies for and as learning across all lessons
Novice	• Clarity of expectations, learning goals, and success criteria	• Variety of formats (e.g., live demos, videos, group work, whiteboard games, slideshows, animations, etc.)	• Varying the level of questions in the provided worksheets (knowledge based, application, and analysis)