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Differentiating Science Instruction: Secondary science teachers' practices

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This descriptive study investigated the implementation practices of secondary science teachers who differentiate instruction. Participants included seven high school science teachers purposefully selected from four different schools located in a mid-Atlantic state. Purposeful selection ensured participants included differentiated instruction (DI) in their lesson implementation. Data included semi-structured interviews and field notes from a minimum of four classroom observations, selected to capture the variety of differentiation strategies employed. These data were analyzed using a constant-comparative approach. Each classroom observation was scored using the validated Differentiated Instruction Implementation Matrix-Modified, which captured both the extent to which critical indicators of DI were present in teachers' instruction and the performance levels at which they engaged in these components of DI. Results indicated participants implemented a variety of differentiation strategies in their classrooms with varying proficiency. Evidence suggested all participants used instructional modifications that required little advance preparation to accommodate differences in students' interests and learning profile. Four of the seven participants implemented more complex instructional strategies that required substantial advance preparation by the teacher. Most significantly, this study provides practical strategies for in-service science teachers beginning to differentiate instruction and recommendations for professional development and preservice science teacher education.

Keywords: *differentiated instruction; secondary science; pedagogy*

Professional science organizations in the USA and beyond have adopted guidelines for science instruction that strive to ensure all students have the opportunity to become scientifically literate while addressing students' varied interest and achievement in

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science (e.g. American Association for the Advancement of Science [AAAS], 1993; Australian Curriculum, Assessment, & Reporting Authority, 2013; National Research Council [NRC], 1996, 2011). These guidelines acknowledge different students achieve understanding in science in a variety of ways with differing degrees of depth and breadth of understanding depending on their interest, ability, and learning context (NRC, 1996, 2011). These reforms specify science instruction should actively engage students in developing conceptual understandings of key science concepts over memorization of facts (AAAS, 1993; NRC, 1996, 2011).

Teachers practicing reform-based instruction place an emphasis on student-centered approaches and flexible curricula. They provide opportunities for students to construct understanding through active learning and give students opportunities to work cooperatively: discussing and debating scientific ideas. These teachers help students develop deeper understandings of how science impacts their everyday world, experience science in ways that help them overcome misconceptions, and focus on scientific investigation. Such instructional approaches facilitate students' of all academic levels success in science (Gallagher, 2006; Koballa & Glynn, 2006; Lee & Luykx, 2006). In reforms-based instruction, the teacher's focus is helping students learn science in response to their own interests and needs, which is consistent with the philosophy of differentiated instruction (DI) (Tomlinson, 2003). This study sought to characterize the experiences of secondary science teachers who differentiate science instruction by observing their classroom practices and exploring their intentions.

Differentiated Instruction

Characterized by instructional practices designed to accommodate students' varied learning needs with the goal of maximizing each student's learning potential, DI is one avenue to address student diversity in science classrooms (e.g. Tomlinson, 2003; Tomlinson & Allan, 2000). As an instructional design model, the primary goal of differentiation is to ensure 'teachers focus on processes … that ensure effective learning for varied individuals' (Tomlinson & McTighe, 2006, p. 3). This is achieved through a well-designed curriculum and student-centered instruction that attends to differences in student readiness, interest, and learning profile (e.g. Tomlinson, 2003; Tomlinson & Allan, 2000; Tomlinson, Brimijoin, & Narvaez, 2008). *Readiness* refers to a student's knowledge, understanding, and skills related to a particular sequence of learning. *Interest* refers to those topics or pursuits that evoke curiosity and passion in a learner. *Learning profile* refers to how a student learns best with regard to their learning style, intelligence preference, culture, and gender (Tomlinson, 2003). Teachers differentiate instruction in response to these student needs by varying access to *content*, the learning *process* (instructional activities), the learning *environment*, or *product* (the way in which a student conveys their understanding of the content), while maintaining the same overall learning objectives for all students.

Theoretical foundations for DI. DI is informed primarily by social constructivist learning theory (Tomlinson & Allan, 2000). Social constructivist-informed instruction includes classroom activities that 'challenge students' suppositions', 'pose problems of emerging relevance', and 'build lessons around primary concepts and big ideas' (Brooks & Brooks, 1999, pp. 35–98). Such instruction emphasizes process, not just the correct answer, by actively engaging students in discussing ideas, interpreting meaning, and constructing knowledge, while providing for individual differences among students (e.g. Bunce, 2001; Gordon, 2008). Effective instruction taps into student interest to foster intrinsic motivation, attends to differences in readiness and learning preference, accounts for students' prior knowledge, provides appropriate entrance points, and continuously integrates formative assessment and feedback (e.g. Bruner, 1966; Tomlinson, 2003; Tomlinson & Allan, 2000). Within a social constructivist framework, students are necessarily placed at the center of the learning process.

Teachers who differentiate instruction engage in social constructivist-aligned teaching practices, acknowledging the importance of students' prior knowledge in the learning process and creating meaningful learning experiences that allow for interactions with other people and the physical environment (Tomlinson & Allan, 2000). In a differentiated classroom, a *focused, high-quality curriculum* provides the foundation for effective instruction that emphasizes conceptual understanding (e.g. Doubet, 2007; Tomlinson et al., 2008). A high-quality curriculum ensures instruction is guided by discipline's key concepts, and is focused, engaging, demanding, and scaffolded (Tomlinson, 2003). *Flexible instructional arrangements* and *respectful tasks* allow for instruction that accommodates differences in how students within a class access and make sense of concepts and for alternative assessment practices (e.g. Tomlinson & Allan, 2000; Tomlinson et al., 2003). *Formative assessment*, an essential component of DI, allows teachers to identify students' prior knowledge and provide effective and timely feedback as the learner is presented with new knowledge (Bell & Cowie, 2001; Black & Wiliam, 1998; Bruner, 1966). Further, ongoing assessment ensures teachers maintain cohesiveness between student needs and the curriculum through their instruction. It helps teachers identify the appropriate entrance point for each student, design instruction that meets students' needs, and provides indicators of student progress. As learning is a social endeavor, creating a *positive social environment* (between teacher and learner and learner and peers) in the classroom ensures students have meaningful opportunities for collaboration for the purpose of constructing knowledge (Staver, 1998). Ultimately, incorporating differentiation strategies into science instruction may facilitate students' access to science content in a manner consistent with the *Framework for K-12 Science Education* (NRC, 2011).

Empirical evidence for DI. Research on DI is still emerging; however, the limited number of studies that exist reveals important conclusions regarding implementation of differentiation strategies in science classrooms. Results of these studies suggest that differentiated science instruction may increase both student achievement and engagement (Richards & Omdal, 2007; Simpkins, Mastropieri, & Scruggs, 2009; Waters, Smeaton, & Burns, 2004). For example, results from two quasi-experimental studies suggest that differentiated science instruction may increase student achievement and engagement, especially in inclusive classrooms at the elementary level (Simpkins et al., 2009). In a quasi-experimental study, Mastropieri et al. (2006) noted learning gains were made by students on achievement tests when DI was employed in middle school science classrooms. In their 2007 study of tiered high school science instruction, Richards and Omdal (2007) reported increases in student achievement for some students, and no decrease in achievement for any student when instruction was differentiated. Similar results were reported by Waters et al. (2004), who studied the impact of differentiated alternative assessments on students' science achievement. Qualitatively, researchers noted students had generally positive perceptions and appeared highly engaged in differentiated activities (Mastropieri et al., 2006; Simpkins et al., 2009; Waters et al., 2004). Further, specific differentiation strategies including flexible grouping, tiering, process differentiation, and alternative assessment appear to lead to positive student achievement in science classes (e.g. Mastropieri et al., 2006; Simpkins et al., 2009; Waters et al., 2004).

Research suggests ideological, institutional, and technical factors influence teachers' success in differentiating science instruction. Teacher beliefs is a well-documented factor that influences whether a teacher will be successful in instructing mixed-ability and differentiated science classes (e.g. Rothenberg, McDermott, & Martin, 1998; Strage & Bol, 1996; Watanabe, Nunes, Mebane, Scalise, & Claesgens, 2007). In order for teachers to spend the time and energy to develop lessons that will attend to the variety of student learning needs in their classrooms, teachers must believe that their work will result in student success. Additionally, cultural factors can act as barriers to successful implementation of DI. In schools where the administration provides a high level of support for teachers by ensuring adequate planning time, fostering collegial relationships among teachers, and supporting on-going and focused professional development, teachers appear to be successful in teaching differentiated science classes. Teachers who are not supported by administration and who lack time, professional development, and professional support from peers do not appear to be as successful (e.g. Doubet, 2007; Strage & Bol, 1996; Watanabe et al., 2007). The literature also indicates teachers need appropriate, effective, and sustained professional development to effectively implement DI (Bain & Parkes, 2006; Doubet, 2007; Dugger, 2008; Halpin-Brunt, 2007; Richards & Omdal, 2007; Simpkins et al., 2009). Finally, material resources, including curricular and instructional materials, appear to be a factor in Mastropieri implementing DI (e.g. Bain & Parkes, 2006; Halpin-Brunt, 2007; Mastropieri et al., 2006). In many studies, instructional materials and differentiated activities were developed by the researchers then implemented by classroom teachers (e.g. Mastropieri et al., 2006). This approach suggests that such curricular materials are not readily available to a broad audience of teachers and may present a barrier to teachers' differentiating instruction.

Barriers to DI are well documented (e.g. Bain & Parkes, 2006; Doubet, 2007; Dugger, 2008; Halpin-Brunt, 2007); therefore, there is a need to further research teachers who successfully differentiate science instruction, and more specifically the beliefs and practices that contribute to their success. Characterization of these teachers' implementation of DI in secondary science classrooms may inform the development of science-specific professional development, a need documented in existing literature (e.g. Bain & Parkes, 2006; Doubet, 2007; Dugger, 2008; Halpin-Brunt, 2007). Further, existing empirical studies tend only to focus on one key aspect of differentiation (e.g. tiering, alternative assessment, flexible grouping, etc.) (e.g. Richards & Omdal, 2007; Waters et al., 2004), rather than presenting an overall picture of a differentiated science classroom that reflects key principles essential to successful differentiation. Thus, descriptive, qualitative research that presents a holistic perspective of how science teachers differentiate instruction at the secondary level could potentially serve as a model for in-service and preservice science teachers and inform professional development. Finally, the majority of the empirical research work associated with DI is focused at the elementary and middle school levels; few practical examples exist for how this instructional model is implemented at the secondary level, and more specifically in science classes.

Secondary science classrooms today are more diverse than ever and science teachers find themselves under pressure from federal and state mandates to provide instruction that ensures the success of all of their students regardless of prior achievement. Therefore, it is important to better understand the strategies, including DI, schools have turned to that may help teachers to meet the learning needs of all students in their classrooms.

The purpose of this study was to characterize how secondary science teachers highly regarded by others in their district differentiate science instruction. Specifically, the study addressed the following research question: How do secondary science teachers implement DI with regard to curriculum, instruction, assessment, and learning environment in their classes?

Methods

Due to the exploratory nature of the research question, we used a case study approach to explore how secondary science teachers implemented DI in their classrooms. Data sources included observation protocol scores and field notes from classroom observations, semi-structured interview responses, and teaching artifacts.

Participants and Context

To identify potential participants, the researchers solicited recommendations for science teachers who effectively differentiate science instruction from district science coordinators, high school principals, and/or science department chairpersons from four school districts in a mid-Atlantic state. These school districts were targeted because district officials indicated teachers in these districts had opportunities to participate in professional development related to DI. This process resulted in a pool of 20 potential participants from five schools. Seven of the identified science teachers agreed

Table 1. Teacher characteristics

Name	School district	School	Years of teaching	Highest degree
Amber	Einstein	Pleasant Fields High School	12	B.S. Biology
Carl	Rutherford	Valley View High School	14	M.T. Physics Education
Diane	Rutherford	Valley View High School	3	M.T. Chemistry
Emily	Fermi	Mountain View High School	4	B.S. Chemistry B.A. Secondary Education
Jamie	Rutherford	Valley View High School	26	M.T. Science Education
Michelle	Einstein	Jefferson High School	11	B.Sc. Kinesiology
Todd	Rutherford	ValleyView High School	5	B.A. Premedical (Biology and Chemistry)

to participate. These purposefully selected participants represent four different high schools from three school districts (Table 1). Two were men and five were women. Their teaching experience ranged from 3 to 26 years. Of these participants, three held advanced degrees.

Data Collection

Interviews, classroom observation field notes, and artifacts, including lesson plans and instructional materials, constituted the primary data sources. This variety of data allowed for triangulation and increased the internal validity of the findings.

Semi-structured interviews. Prior to classroom observations, the first author conducted one-hour semi-structured interviews with each participant. Content and face validity of the interview protocol were evaluated by an expert panel in science education and DI. Suggested revisions were taken into account and changes were incorporated into the final protocol. The interview included 17 open-ended questions designed to elucidate participants' professional background, beliefs about science teaching and learning, and general knowledge and use of DI. Initial questions explored each participant's perceptions of how students learn science most effectively, their perceptions of student and teacher roles in the classroom, and the role of external factors (e.g. state and national science standards, end-of-course assessment) on science instruction. Additional questions addressed DI, including perceptions of the philosophy of DI, the participant's extent of exposure to professional development related to DI, and examples of differentiated lessons taught by the participant. Data from this interview helped to frame classroom observations. Each interview was recorded and transcribed for analysis by the first author.

Table 2. Classroom observations

Name	Content-area observed	Number of observations
Amber	Biology	5
Carl	Physics	4
Diane	Biology	3
	Chemistry	4
Emily	Chemistry	3
	Physics	3
Jamie	Chemistry	4
Michelle	Biology	5
Todd	Earth Science	4

Classroom observations. The first author observed each of the seven participants a minimum of four times, for a total of at least six hours of classroom observation per teacher (Table 2). To capture variations in participants' instruction across courses, participants who taught only one course were observed four or five times and participants who taught multiple courses (e.g. Earth Science and Biology) were observed three or four times for each course they taught. Observations were scheduled based on when the participant indicated an intention to incorporate differentiation strategies into instruction. The goal of these observations was to ascertain the extent to which participants differentiated their science instruction and to capture the variety of differentiation strategies employed. A flexible observational frame guided detailed field notes that addressed lesson flow and content, instructional approaches, evidence of differentiation, student/teacher interactions, and students' affective responses to instruction. To increase the internal validity of the findings, member checks (e.g. informal interviews and lesson debriefs) were conducted following observed lessons to ensure initial impressions and analyses accurately reflected the teachers' perceptions.

Observation protocol. In addition to field notes, immediately following each observation the observed lesson was rated using a modified version of the Differentiated Instruction Implementation Matrix (DIIM) (Downes, 2006). This instrument, grounded in observation protocols by Tomlinson and Strickland, is well-aligned with the conceptual framework of DI, described above. It captures the extent to which critical indicators of DI (e.g. focused, high-quality curriculum, flexible instructional tasks, ongoing formative assessment, positive social environment) were present and the performance level at which teachers engaged in these elements of DI (Downes, 2006). To establish content and face validity of the DIIM for this study, an expert panel in science education and DI reviewed the instrument and suggested modifications, which were incorporated into the instrument. Two iterations of review by the panel resulted in the validated instrument, the Differentiated Instruction Implementation Matrix-Modified (DIIM-M), used in the study (Maeng & Bell, 2012).

The DIIM-M includes 25 differentiation criteria across seven domains. Each of these domains contains three to six criteria for that domain and corresponds to the key indicators of a differentiated classroom (e.g. Doubet, 2007; Tomlinson, 2003). The *quality curriculum and lesson design* domain indicates the presence of a focused, high-quality curriculum. The *planning and response to learner needs* and *student assessment* domains correspond to the extent to which teachers emphasize ongoing formative assessment practices during instruction and the *instructional practices* and *classroom routines* relate to teachers' capacity to develop and implement respectful tasks and flexible instructional arrangements for students. The *positive, supportive learning environment* domain reflects the extent to which the teacher fosters a classroom environment that results in a positive community of learners.

For each category in each domain, quality indicators are given for four different levels of proficiency: novice, apprentice, practitioner, and expert. A category for 'not observed' indicated if the criterion was not applicable to the lesson and therefore not observed during the lesson. If a criterion was applicable to a lesson, but not observed, this was rated at the novice level. For ease in descriptive analysis, numeric values 0 (not observed), 1 (novice), 2 (apprentice), 3 (practitioner), and 4 (expert) were assigned and recorded.

Lesson plans and instructional materials. Collected unit plans, lesson plans, and other instructional materials (worksheets, teacher presentations, rubrics, and laboratory sheets) served as artifacts to ascertain participants' instructional goals for lessons and both planned and informal formative assessment strategies. They were used to validate statements made by participants during interviews and to focus and provide the context classroom observations.

Data Analysis

In order to quantify the extent to which critical indicators of DI were present for each participant, means were calculated across all observations for each of the criteria, as well as for each domain on the DIIM-M. Additionally, the overall DIIM-M mean, which represented the mean across all domains, was calculated for each participant. The qualitative analysis software NVIVO-8 was used to analyze transcripts of observation field notes, lesson plans and other artifacts, and interviews. This analysis followed an inductive, constant-comparative approach, as described by Bogdan and Biklen (2007). Observational data, interviews, and artifacts, such as lesson plans and worksheets provided a number of data sources through which the data were triangulated (Lincoln & Guba, 1985). Drawing upon these different data sources during category generation and refinement resulted in categories and hypotheses about relationships between categories well-grounded in the data corpus. First, these data were searched for examples of differentiation strategies employed by participants (e.g. grouping structure, order of activities, varying materials, format for conveying concepts/skills). This search for elements of DI in each participant's instruction was guided by the theoretical framework and Tomlinson's (2003) model of differentiation. The resulting subset of data underwent another round of analysis in which individual instances were coded to reflect the differentiation strategies employed by each participant (e.g. interest, learning preference, process, product). Ultimately, these codes led to the development of preliminary categories of differentiation strategies employed by each participant (e.g. providing choice, learning menu, tiering, grouping). The entire data set was then re-examined and it was determined that each of these preliminary categories fit into two overarching categories: minor modifications to instruction and complex differentiation strategies. These categories and supporting evidence, in the form of quotations, observation field notes and analytic vignettes, which provide illustrative examples of interpretations, are presented below.

Results

In this section, we characterize participants' DI as overall and individual trends in participants' DIIM-M scores followed by qualitative description of the variety of differentiation strategies employed.

DIIM-M Scores

Analysis of the DIIM-M and field notes revealed the extent to which critical indicators of DI were present in participants' instruction. An overall mean and standard deviation on the DIIM-M was calculated across all criteria and observed lessons for each teacher (Table 3). Diane scored the highest average overall (2.9 points) on the DIIM-M and Carl scored the lowest (1.8 points) on the instrument. The overall DIIM-M means suggested that Diane and Michelle, who scored an average of 2.9 points and 2.5 points, respectively, across all lessons observed, were the most proficient at differentiating instruction.

Table 3. Domain DIIM-M means by teacher

	Domain						
Teacher	1 M (SD)	2 M (SD)	3 M (SD)	4 M (SD)	5 M (SD)	6 M (SD)	7 M (SD)
Diane	3.2 (.44)	2.9 (1.1)	2.8 (.69)	2.7 (.84)	3.0 (.47)	2.9 (.95)	2.7 (1.2)
Michelle	3.2 (.68)	1.3 (.49)	2.7 (.46)	2.5 (.74)	2.6 (.53)	3.0 (.98)	1.8 (1.0)
Amber	3.0 (.76)	1.3 (.49)	2.6 (.71)	2.3 (.89)	2.6 (.53)	2.5 (.92)	1.6 (.74)
Jamie	3.3 (.45)	1.2 (.39)	2.4 (.60)	2.1 (1.1)	2.5 (.55)	2.2 (.81)	1.0 (0)
Emily	2.8 (.43)	1.4 (.61)	2.3 (.70)	1.9 (.92)	2.6 (.69)	2.4 (.90)	1.4 (.74)
Todd	2.9 (.51)	1.3 (.49)	2.2 (.52)	1.6 (.65)	2.4 (.74)	1.8 (.55)	1.4 (.55)
Carl	2.3 (.75)	1.0 (0)	2.0 (.79)	1.8 (.79)	1.8 (.45)	1.9 (.64)	1.5 (.58)

Note: Domain names: 1, quality curriculum and lesson design; 2, planning and response to learner needs; 3, instructional practices; 4, classroom routines; 5, student assessment; 6, positive, supportive learning environment; 7, evidence of differentiation.

Analysis of the DIIM-M by domain provided a more detailed description of teachers' differentiation practices, as each domain addressed a key feature of DI (Table 3). The following discussion of results focuses primarily on positive outcomes, as the emphasis of this study was on successful differentiation practices. Diane, Michelle, and Jamie had the highest means of all of the teachers on at least one domain. Diane had the highest mean on five of the seven domains: *Planning and Response to Learner Needs, Instructional Practices, Classroom Routines, Student, Assessment, and Evidence of Differentiation.* Michelle had the second highest overall mean and the highest mean on *Positive, Supportive Learning Environment.* Jamie had the highest mean on *Quality Curriculum and Lesson Design* and had the fourth highest mean on the instrument.

Each participant's highest rating was for *Domain 1: Quality Curriculum and Lesson Design*. This domain addressed the quality of objectives, communicating these to students, and alignment between objectives and activities. All of the participants articulated learning objectives for each lesson and most observed instruction appeared to be aligned with these stated objectives. Averaged across all observed lessons, Jamie scored the highest, 3.3 points, on this domain. In particular, Jamie's expectations for what students should understand, know, and be able to do by the end of each unit were clearly outlined on a unit objectives sheet. These stated objectives addressed meaningful science content and Jamie gave these to students at the beginning of the unit and consistently referred to these objectives during lessons, indicating which objectives they were working on within a given lesson.

Across all participants, the means on the domains corresponding with formative assessment practices (*Domain 2: Planning and Response to Learner Needs* and *Domain 5: Student Assessment*) were the lowest. Diane's mean score of 2.9 points on *Domain 2: Preparation for Learning and Response to Learner Needs* reflected her planning lessons that consider various students' needs, as well as the specific needs of struggling and advanced learners. Diane consistently used preassessment or formative assessment data to group students and to provide appropriately challenging activities for them. Results of classroom observations suggest Todd and Emily were the only other teachers who implemented planned activities that explicitly addressed the varied needs of advanced and struggling learners.

Domain 3: Instructional Practices assesses lesson organization, instructional strategies employed, the potential for student engagement, and intellectual development. Diane's mean of 2.8 points was the highest of all of the participants. Lessons planned by Diane were engaging, presented content in a logical progression, employed student-centered instructional strategies, frequently tapped into students' prior knowledge or tied science content to students' everyday life, and provided opportunities for all learners to be successful.

Means for all of the teachers on *Domain 4: Classroom Routines* ranged from 1.6 points to 2.7 points. This domain addressed teachers' flexibility in grouping students, use of space and resources, clarity of directions, and classroom management. Diane rated the highest on this domain. Even as a variety of different activities were occurring in Diane's classroom simultaneously, it was a structured and productive learning environment.

Domain 5: Student Assessment addressed the use of formative assessment and rubrics within a lesson. Participants' means on this domain ranged from 1.8 points to 3.0 points. All of the teachers conducted informal formative assessments to some extent; information gleaned from these assessments was typically used by participants to gauge student understanding, inform whole-class instruction, and to adjust lesson pacing. Diane used formative assessments extensively to inform how she grouped students and what activities they completed. Frequently, she conducted these assessments within a single class period using a classroom response system (clickers) and used the information to guide instruction later in the same class period. Diane, Jamie, and Emily made frequent use of guidelines, typically in the form of verbal or written directions for assignment completion and Michelle, Amber, and Todd used rubrics extensively in their classrooms to inform students of expectations for assignments. In lessons where these tools were used to guide students, they typically were teacher-generated ahead of the lesson with no student input.

Domain 6: Positive, Supportive Learning Environment assessed the overall nature of the classroom environment. Michelle, who had the second highest mean across all observed lessons, scored the highest of all of the teachers, 3.0 points. She demonstrated a high degree of knowledge of individual students' interests and academic and social backgrounds. She promoted collaboration and fostered community in her classroom through her interactions with students and her expectations of students' interactions with each other. Evidence from classroom observations indicated Diane had the second highest mean DIIM-M score of 2.9 points in this domain. Classroom observation data suggested Diane, like Michelle, exhibited many behaviors that indicated she acknowledged her students' various backgrounds, fostered collaboration, and facilitated, rather than directed student activity in the classroom.

On *Domain 7: Evidence of Differentiation,* Diane scored the highest of all of the teachers, earning an average of 2.7 points in this domain. It was uncommon to observe teachers differentiating two different elements (i.e. content and process, content, and product) within the same lesson. However, in almost every lesson observed, Diane provided students with multiple ways to engage with content or process based on differences in their readiness or learning profile, which she ascertained through formative and pre-assessment. Yet, there is no evidence from classroom observations to suggest she provided opportunities for students to create products to express their understanding. Michelle also provided multiple avenues for her students to engage in sense-making activities that were differentiated by learning profile. Amber and Emily were observed providing students opportunities to create a product and only Amber provided multiple ways for students to express their understandings of content through a product. There was no observation evidence to suggest that Jamie differentiated content, process, or product in meaningful ways for her students. The particular activities implemented by participants that differentiated content, process, and/or product in substantive ways are described below in the section entitled complex differentiation strategies.

Breadth of Differentiation Strategies Employed

Qualitative analysis of classroom observations and interviews revealed these seven teachers implemented a variety of differentiation strategies in their classrooms. Evidence from field notes suggest all of the teachers primarily used instructional modifications that required little advance preparation, referred to hereafter as low-preparation modification, on the part of the teacher to accommodate differences in students' interests and learning profile. A subset of the participants implemented more complex instructional strategies that required substantial advance preparation on the part of the teacher.

Low-preparation modifications to instruction. Evidence from the 35 classroom observations suggests that all of the participants regularly integrated at least one low-preparation differentiation strategy into their instruction to attend to students' interest or learning profile (Table 4). These strategies typically took the form of teachers giving students flexibility in making decisions about their learning environment and how they worked on and completed instructional activities. In many cases, the teachers integrated more than one opportunity for student choice into a given lesson.

Four of the teachers (Diane, Michelle, Amber, and Carl) let students choose their seats. During at least one observed lesson of each teacher, students were given a choice of working individually or in small groups on instructional activities. Teachers also frequently let students choose who they wanted to work with on activities and laboratories. As Amber explained, 'They have choices as to who is in their group. They

Table 4. Low-preparation differentiation strategies employed by participants

Differentiation strategy		Student characteristic	Teacher(s)
Choice	Working individually or in small groups	Learning profile	Diane, Michelle, Amber, Emily, Jamie, Carl, Todd
	Where students sit in the classroom	Learning profile	Diane, Michelle, Amber, Carl
	Who students work with	Learning profile	Diane, Michelle, Amber, Carl, Emily, Todd
	Order in which activities are completed (stations)	Learning profile	Michelle, Todd
	Providing a variety of materials for completing activities	Learning profile, Interest	Diane, Michelle, Amber
	Letting students select the format in which they convey understanding of a concept/skill to the teacher	Learning profile	Diane, Todd

can choose where they sit' (Amber, Interview 1). Michelle described how this works in her classroom, 'We do a lot of group work. I try not to construct their groups for them. When we're doing review worksheets, study guides, things like that, they're allowed to move and sit with other people' (Michelle, Interview).

Other modifications included letting students choose the order in which they completed a series of related activities. Typically lessons incorporating this strategy also included contextualized or authentic experiences or using multiple examples that match different learning styles. For example, Todd explained that he believes the best way to learn Earth Science is by being out in the field, so he frequently took his students outside to explore the school grounds for evidence and examples of the content they are learning about inside the classroom. In one lesson, Todd took his Earth Science class out to the football field to explore the 'earth's changing surface'. He described the purpose of this lesson both from a pedagogical perspective and from a content perspective,

> Hopefully it will be a great lesson because sometimes there's no connection between what happens in this room and the rest of the world. We're going to be out of the school looking on school grounds looking for examples of their vocabulary words. They'll draw them, locate them, photograph them. (Todd, Interview)

In addition to providing an authentic context for his students to make connections between the science content they were learning about in class to real-world examples found within their school community, Todd integrated a variety opportunities for student choice into the lesson:

> Once at the football field, students worked in self-selected small groups to look for evidence of mechanical and chemical weathering, erosion, permeable and impermeable surfaces, a 'watershed' divide, and evidence of soil creep. They also designed a short experiment to answer the question, 'Does water flow through sand or clay more quickly?' Finally, they answered questions about human impact on the topography of the school property, including, 'What erosion and soil conservation techniques have engineers of this stadium used? Were they effective? Why or why not?' and 'What is something you would change about the stadium design? Why?' Students chose how to record and convey their observations—through descriptive text, pictures, or diagrams. Further students worked through the activities and answered the questions in whatever order suited them. (Todd, Observation 3)

In this lesson, students chose who they worked with to complete the activities, the order in which they completed the nine activities, and how they recorded their observations and answered the questions.

In a similar way, Michelle's biology class students completed a variety of activities intentionally selected by Michelle to provide students variation in reviewing content based on students' perceived learning preferences. These included completing riddles about cell organelles, answering questions about cell transport, creating a clay model of a cell membrane that included an integral membrane protein channel, and creating a Venn diagram illustrating the similarities and differences between organelles in plant and animal cells (Michelle, Observation 4). The variety of tasks

Michelle incorporated into this lesson all related to cell structure and function. Creating a model was a creative, kinesthetic task, writing riddles was a creative, verbal way of reviewing information, answering questions also suited her verbal students, and creating a Venn diagram appealed to her students that preferred learning through a more analytic approach. Although students completed all of the tasks, Michelle integrated choice into the lesson—students completed the tasks in any order they wished.

Teachers also gave students access to a variety of resources and materials for students to complete assignments. Diane, Amber, and Michelle had magazines, poster-paper, markers, and colored pencils for students to use in completing assignments. Additionally, students in Diane's class had access to computers to use as needed to look up information. Amber's students also had access to a variety of materials and she encouraged her students to use them as they worked on small in-class projects like the one in the following example:

> After learning about the functions of cell organelles, students in Amber's Biology class created posters in which they drew a cell and the organelles found within the cell. They cut out images from magazines and newspapers that served as analogies for the organelle's function. Each student had different images and corresponding analogies for the organelles. For example, Isabelle glued a picture of a chair with a stuffed frog next to the cell wall and wrote, 'The chair supports the frog like the cell wall supports the cell.' Maggie used an advertisement for shoes and drew a line to the cell membrane. To explain the connection between the cell membrane and the shoes, she wrote, 'Shoes protect your feet like the cell membrane protects the cell.' Mike used a picture of a football player to explain the function of the nucleus, writing, 'The quarterback is the leader of the football team and tells the rest of the team what to do like the nucleus tells the cell what to do'. (Amber, Observation 2)

In this creative application task, Amber's students had access to a variety of what allowed them to explicate the connections between their own experience, interests, and background knowledge and the different functions of cell organelles.

Overall, each teacher in the study incorporated one or more minor modifications to their instruction that constituted differentiation by interest or learning profile. These strategies primarily provided students with choices about their learning environment and how they worked on and completed instructional activities.

Complex differentiation strategies. While there is substantial evidence to suggest all of the participants employed low-preparation differentiation strategies related to learning profile and interest, only four participants implemented lessons that incorporated complex differentiation strategies that required substantial advanced planning by the teacher (Table 5). These lessons were differentiated in substantial ways by content, process, or product to accommodate variations in students' learning profile or readiness. There were no observational data that suggested participants used complex approaches to differentiate for student interest. Further, Jamie, Carl, and Todd were not observed implementing complex differentiation strategies. Diane employed complex differentiation strategies more frequently than the other teachers; therefore, her instruction is represented in a greater number of examples in the following sections.

Table 5. Complex differentiation strategies employed by participants

Differentiation strategy	Student characteristic	Curricular modification	Teacher (s)	Content taught
Learning menu	Learning profile	Product	Amber	Characteristics of classes found in Kingdom Animalia
Choice	Learning profile	Process	Michelle	Photosynthesis review: create a review sheet or poster
		Content, process	Diane	Three options—'Read it', 'See it/Feel it', 'Research it'
Tiering	Readiness	Process	Emily	Identification of unknown solutions
Flexible grouping based on formative assessment data	Readiness	Process	Diane	Properties of solutions and concentration
		Process		Final SOL review: students move through topical groups in which one student is the leader. Every student is the leader at least once; not all students move through every topic

Learning profile differentiation. In these lessons, teachers planned instructional activities that attended to differences in students' learning profiles by differentiating content, process, or product. For example, Amber integrated a learning menu, differentiated by product, on characteristics of animal kingdoms into her Classification of Life unit. While reviewing photosynthesis with her class, Michelle's students had the choice of completing a review sheet or creating a poster that incorporated key ideas about photosynthesis, an example of differentiation by process. Diane provided her students an opportunity to choose from three options to access and practice with content in a number of lessons. All of the teachers who implemented complex activities differentiated by learning profile provided the students with options for interacting with the science content and let the students choose the option with which they were most comfortable.

In an example of a lesson differentiated for learning profile, Amber designed a learning menu for her Biology students in which they worked through a series of options to learn about the animal kingdom. This lesson took place over three and one-half class periods, roughly five instructional hours and was differentiated for learning profile. Amber described the different parts of the learning menu and provided guidelines for completing each part to her students, as described in the following classroom example:

> Amber says to the class, 'Everyone in the group needs to fill out this chart.' She holds up the packet containing the overview of the learning menu, the first page of which is the 'appetizer' portion of the learning menu. For each class of animals, which are separated as vertebrates or invertebrates, students identify the habitat, movement, symmetry/

> segmentation, reproduction, and nutrition on a chart. There is also a space to provide examples of specific species that fell within that class. Next, Amber describes the 'entrée' of the learning menu, in which students choose from one of three choices: create a storybook, create a movie/video, or create an activity/coloring book. Amber says to the class, 'I'm adding a fourth choice. You can make a music video. You need to write the song, have music, and then have the video. That's a different thing than those other three.' A student asks, 'Can we rap?' Amber responds, 'I'm trying to reach everyone. You have a storybook, must have a plot. The activity book is not just a coloring book. It has to have activities that teach the information. If you're doing a coloring book you need to draw the pictures. You can make the crosswords, word searches you can do those on Puzzle Maker. Your group can really do anything you're interested in, just let me know. Then everyone must critique two projects.' The 'side dish' of the learning menu is to individually choose two to critique: a storybook, a movie, an activity book. She continues with directions, 'And if you want to do the extra credit, the 'dessert' of the storybook, it's to work individually to create a test to assess knowledge of vertebrates and invertebrates. This is the info you have to include.' She holds up the last page of the learning menu packet, which includes the tasks for the 'entrée' and the rubric. 'That's how it will be graded. You have a rubric. You have through this week to work on it. You'll have access to the computers tomorrow.' The students move so they can work with their partners, which they chose the previous class. Amber circulates among the students, asks each group what they are planning to do for their 'entrée' and writes this down on a list. Five groups choose to do an activity book, one group selects a storybook, three groups choose the video option, and one group is doing a music video. (Amber, Observation 5)

In this lesson, students selected their workmates, the format through which they conveyed understanding, and the products they critiqued. Students synthesized information about characteristics of different animal classes using their notes, textbook, and prior knowledge. Each of the options provided groups the opportunity to apply their content knowledge of the characteristics of different classes of animals and convey their understanding in a creative format. Finally, students evaluated their peers' projects, using the same rubric Amber planned to use to evaluate their 'entrée'.

In another example, Michelle gave her students the option of creating a review sheet or a poster as a review for a test on photosynthesis. The review sheet was designed for students who wanted to apply the information they learned about photosynthesis in a more analytical/verbal manner. These students developed fill-in-the-blank questions, diagrams, or short answer questions to cover the important information including where it happens in the plant and what happens in each stage of photosynthesis. They also created a separate answer key for their review. The poster option provided students with a more creative way to review photosynthesis. Students could do lots of little pictures or one big picture, but they had to include the equation and identify what goes in and what comes out and what happens in each stage. Michelle provided access to a variety of creative materials including markers, pencils, colored pencils, big paper, crayons, and stencils. Students had approximately 45 minutes of class to complete the activity of their choice. Of the class, four students chose to write a review. The other 19 students all opted to make a poster (Michelle, Observation 3).

Similarly, Diane's students frequently had the opportunity to select from three preplanned options, designed to let students access and apply the content of the lesson based on learning profiles. While the three options were differentiated by learning profile, all of the students worked toward the same lesson objectives, which were clearly delineated for the students. Diane referred to the first option as 'read it', which was designed for more students who appreciated more verbal, independent work. Students completing this option read information pertaining to lesson's objectives, completed a reading guide, and answered supplemental questions. Students choosing to complete this option primarily worked independently at a large table in the back of Diane's classroom, although they frequently discussed questions with their peers who also selected this option. The second option, designed for audio, visual, and kinesthetic learners, was the 'see it/hear it/feel it' option. Students selecting this option worked closely with Diane near the computer, projector, and SmartBoard™ located in the front of Diane's classroom. Instruction in this format was more teacher-guided, in that students took notes from a PowerPoint™ presentation, engaged in discussions about content, and completed activities in small groups. Diane designed the 'research it' option for students who wanted to work independently or in partners to explore content in a flexible, less linear manner. Students in this group answered the essential questions of the lesson by reading from the textbook, finding information on the Internet, and/or going to the library, then synthesizing what they learned into a coherent whole. This often took the form of free-form notes answering the questions, posters, and collages. Diane frequently made use of this strategy. Overall, of the four teachers who incorporated complex differentiation strategies into their instruction, three of them differentiated by learning profile.

Readiness differentiation. Emily and Diane both taught lessons that were differentiated for student readiness. Emily's Chemistry students conducted a tiered micro-scale laboratory activity. Emily assigned students to the two different tiers based on her perception of their need for scaffolding during the activity. Emily's Chemistry students conducted a tiered laboratory activity in which they recorded observations of patterns of mixing between 12 known solutions. Then, they were given eight unknown solutions to identify. While all of the students completed the 'knowns' part of the activity in the same way, in an interview, Emily explained how she modified the 'unknowns' portion of the laboratory activity to account for differences in student readiness.

> To my more advanced students, I'll give a series of eight unknowns and they have to tell what each one is and they get one shot at it. To my students having a hard time, I'll give them four unknowns and they can periodically check [with me to see if they've figured out what chemical it is]. I make them justify, 'Why do you think this is this?' So they have to go back and say, 'When calcium reacted with this then I thought this.' And so on and so forth. (Emily, Interview)

In this tiered lesson, all of the students were tasked with the same goal; determine the identity of the unknown solutions through their patterns of mixing. All of the students, regardless of whether they had four or eight unknowns to identify, had to use their knowledge of solubility rules and observation skills. The variation in the tiers was in the degree of scaffolding Emily provided for students to identify the unknown.

In a unit on solutions, Diane used a formative/preassessment to group students according to whether or not they needed more practice with molarity and dilution calculations, compacting the curriculum for those students who did not need more practice, as described in the example below:

> After teaching her students about concentration, molarity, and dilution and giving her students a few days to practice use their new knowledge, Diane gave her students a short ungraded quiz to assess their understanding and ability to apply the relevant equations. She also included questions about colligative properties as a preassessment of the content she planned to introduce later in the period. Her students completed the quiz on a classroom response system. Diane was immediately able to see individual students' results and she used the information to group students according to whether they needed more practice solving molarity and dilution problems or if they were ready to move on to the next topic, colligative properties. For example, the three students who did not miss any questions did not have to complete the molarity sheet. Rather, they began working on a reading guide for colligative properties. For the students who needed more practice with molarity, she handed out a sheet of practice problems noting that 'since everyone did well on question four, no one needs to do the back of the sheet.' For the next 25 minutes, Diane circulated between all of the table groups, answering questions both from students working to solve molarity and dilution problems and those beginning to work on colligative properties. Once the group working the practice problems had checked their work, she gave the students completing the reading the option of either continuing to work at their own pace or joining the rest of the class to learn about colligative properties through PowerPoint™ presentation and discussion. All three of these students decided to join the rest of the class for the PowerPoint™ and discussion. (Diane, Observation 3)

In this lesson, Diane used formative assessment data to determine whether students were ready to move on to new content within the unit. For those students who mastered molarity and dilution calculations, she provided a means for them to learn new content at their own pace instead of continuing to practice a skill they had mastered.

In another example in which Diane differentiated instruction by student readiness, Diane created and implemented a differentiated review activity to prepare her Chemistry students for the upcoming state end-of-course tests. In this activity, Diane divided her students into flexible groups based on the results of a practice cumulative assessment that covered all of the concepts the students learned during the year. For example, in the first rotation, the six groups in her Chemistry class were identified as, a 'general' group that missed a lot of the basic questions, mixed math, stoichiometry, periodic table, atoms, and moles. Each of these groups contained three to six students who scored low in this area on the formative assessment and also included at least one 'expert' student who scored highly on that portion of the practice assessment. While the experts were expected to participate in the group discussions about problems, the expert was also the group facilitator and initial 'go to' person if the rest of the members of the group were not able to figure out an answer to a practice problem. Students discussed and worked together in these groups to provide solutions to a number of conceptual and practice problems related to their concept, as described in the example below:

> After explaining how the activity was going to work, Diane assigned each group to a table in the classroom and students moved to these tables. Diane said to the class after providing them with practice problems related to the content their group was assigned, 'Work on the practice at your table and after about half an hour we'll see if we're ready to move on. If you finish early—if your group gets done with all your questions, let me know and I can give you guys more to review or you go back and look at your notes on that section. You're focusing on what you need help with. Work together as a team to figure this out. When your group finishes, let me know and I'll check what you've done.' Diane spends the next 30 minutes circulating between groups assisting them as necessary, intervening if the student experts need her support, and checking students' answers. Few students are off task during this time; most conversations between members of a group relate to solving the practice problems, although some address broader understandings of the concepts. After about 30 minutes, Diane assigned students to new topic groups and assigned new experts to these groups. Thus, the students switched both groups and concepts, moving on to review another Chemistry topic that assessment data indicated they needed to review. The 'experts' also changed as the groups changed, such that most of the students in the class served as the 'expert' for at least one group. This review activity continued over the course of three class 90-minute block periods. (Diane, Observation 6)

This lesson is an example of proactive planning on the part of Diane to meet the needs of her students. Diane used formative assessment data to determine students' individual strengths and weaknesses based on student performance on a practice cumulative assessment. While planning the lesson, she used these data to establish review groups based on both students' strengths and weaknesses prior to instruction. Thus, the process through which students engaged with content was differentiated to account for variations in student readiness. Additionally, by rotating both group members and group 'experts', Diane fostered a classroom environment where both individual and collective success was valued.

The results of this study indicate all seven participants incorporated a variety of low-preparation differentiation strategies to provide students with choice with respect to interest and learning preference. Further, four participants incorporated complex strategies requiring substantial advanced planning to differentiate for learning profile or readiness.

Discussion

This study explored how secondary science teachers implemented DI in their classrooms. Specifically, it contributes to the existing literature by documenting the practices of secondary science teachers who differentiate instruction by holistically characterizing their practices rather than focusing on only one aspect of differentiation (e.g. tiering, alternative assessment, flexible grouping, differentiating process by readiness). Further, it explored the role key features of DI (focused high-quality curriculum, ongoing formative assessment, positive community of learners, flexible instructional arrangements, and respectful tasks for students) played in these teachers' proficiency in differentiating instruction (Doubet, 2007; Tomlinson, 2003; Tomlinson et al., 2008).

Previous research (e.g. Mastropieri et al., 2006; Richards & Omdal, 2007; Simpkins et al., 2009; Waters et al., 2004) indicates that student affect and achievement may be positively influenced by DI. Each of these studies explored a specific differentiated instructional strategy on student outcomes: tiering (e.g. Mastropieri et al., 2006; Richards & Omdal, 2007; Simpkins et al., 2009) and differentiated alternative assessment (e.g. Waters et al., 2004). However, unlike the present investigation, these investigations did not explore teacher enactment of differentiation strategies in the secondary science classroom. In addition, the tiered activities (e.g. Mastropieri et al., 2006; Richards & Omdal, 2007; Simpkins et al., 2009) were designed by research teams and implemented by classroom teachers with coaching; whereas in the present investigation, all of the low-preparation and complex differentiation strategies employed (learning menus, choice, tiering, and flexible grouping based on formative assessment data) were designed and implemented by the participants. While the present investigation explores teacher rather than student outcomes, it adds to the body of literature on DI by providing a clearer picture of what DI looks like when implemented in secondary classrooms and provides examples of how a variety of differentiated strategies were enacted in secondary science teachers' classrooms.

Since all seven teachers were purposefully selected for this study based on the recommendation of district and school administrators familiar with their instruction, it is not surprising that each of them incorporated differentiation strategies into their instruction to some extent. Additionally, the teachers themselves suggested representative lessons or units for observation they believed reflected the differentiation strategies that typified their instruction throughout the academic year. Thus, in addition to the variety of strategies employed by the participants, evidence from classroom observations indicated the strengths and weaknesses that most likely typified each participant's differentiated science instruction.

Six domains of the DIIM-M correspond to the key principles of DI: quality curriculum and lesson design planning and response to learner needs, instructional practices, classroom routines, student assessment, and positive, supportive learning environment (e.g. Doubet, 2007; Tomlinson, 2003). The final domain relates to participants' proficiency in employing complex differentiation for content, process, and product. Out of the seven domains, each participant scored highest on the *quality curriculum and lesson design* domain. This indicates instructional activities were clearly linked to learning objectives informed by state and national standards and that these activities were designed to develop students' understanding of the important ideas of the content. However, scores relating to formative assessment practices were lowest for all but two participants. Participants' lack of formative assessment in the present study is consistent with the results of studies by Daws and Singh (1996, 1999) and Morrison and Lederman (2003), which reported that science teachers have difficulty in using formative assessment practices to design effective instruction. Given the importance of formative assessment in differentiating instruction (Doubet, 2007), it is not surprising that participants who scored low on this domain, including Jamie and Emily, also scored low on the *evidence of differentiation* domain, which assessed participants' proficiency in designing and implementing more complex differentiation strategies.

All of the participants implemented low-preparation differentiation strategies that attended to differences in student interest and learning profile over instructional strategies that addressed variations in student readiness and used existing resources as the basis for activities differentiated by learning profile and interest. This finding does not satisfy the recommendation of Tomlinson (2003), who emphasized equal attention to students' varied interests, learning profile, and readiness in planning and implementing DI. However, these results provide further support for findings by Johnsen, Haensly, Ryser, and Ford (2002) and Brighton, Hertberg, Moon, Tomlinson, and Callahan (2005). In a two-year evaluation of a professional development program designed to teach elementary school teachers to differentiate instruction for gifted students, Johnsen and colleagues reported that teachers began with modifications for learning preference and classroom environment and moved gradually toward modifying instruction to accommodate variations in student readiness. Brighton et al. (2005) found similar trends among middle school teachers engaged in a professional development program designed to help them differentiate instruction. Taken with the results of the present study, the results of these studies suggest that starting with learning preference may facilitate teachers' incorporation of differentiation strategies.

It is probable that failure to use formative assessment data to plan instructional activities prevented most participants in the present study from incorporating activities differentiated for variations in student readiness. Doubet (2007) reported similar findings among the high school teachers in her study. She noted the central role of formative assessment in effective differentiation and their struggle to effectively use the data resulting from formative assessments to plan instruction. Readiness differentiation requires a combination of effective formative assessment strategies to identify students' academic needs and the capacity to plan and implement multiple activities that allow students to meet the same learning objectives through support and scaffolding appropriate for each student's identified learning needs (Tomlinson, 2003).

The results suggest that all of the participants in the present study have room to grow, particularly with respect to DI that supports the cultural aspects of learning profile differentiation, the use of complex differentiation strategies, and readiness differentiation. All seven teachers emphasized learning styles over culture in designing instruction that attended to students' learning profile. In fact, there was no evidence that they took into account students' cultural background when designing activities differentiated for learning profile. Rather, participants most frequently offered varied working arrangements and activities that differed in the mode of content presentation. Tomlinson and Imbeau (2010) assert that incorporating teaching strategies that reflect culture-based patterns of learning may facilitate students' academic growth (p. 18). In a science classroom, this may include having students explore science content within an authentic context or contextualized within a real-world problem affecting their local community. Further, attention to students' cultural differences during instruction may improve their attitude toward science and success in science courses (e.g. Aikenhead & Jegede, 1999; Osborne, Simon, & Collins, 2003).

Implications

The results of the present study have numerous implications for practicing teachers, school and district officials, policy-makers, science teacher educators, and those designing professional development for science teachers.

In-service science teachers who would like to begin differentiating instruction will find that the results of this study provide them with practical strategies they can apply in their own classrooms. All of the teachers used low-preparation strategies to differentiate for students' varied learning preferences and interest. The majority of participants established a strong rapport with students and a positive learning environment. Establishing relationships with students and sending them a consistent message that the teacher is present to facilitate student success helps teachers build a classroom community grounded in mutual respect. It is important that teachers recognize that there are a variety of ways in which they can begin to identify their students' academic needs and work toward instructional practices that are responsive to those needs.

Addressing the logistical aspects of differentiation such as the use of space and classroom management is also important. Teachers should brainstorm ways to use their existing classroom space creatively to facilitate whole-class, small group, and individual instruction and transitions between these groups. Having a structured classroom routine for students to follow and specific locations in which materials are located and recurring activities occur (i.e. specific reading groups, groups working directly with the teacher, students working individually) aids in classroom management, as does planning opportunities to check in with all students into the structure of the lesson.

It is significant that all of the participants in this study were recommended for this study based on the perception that these teachers differentiated instruction. However, only one teacher, Diane, regularly incorporated a variety of differentiation strategies into instruction. The majority of participants employed only low-preparation strategies and many did not integrate formative assessment practices effectively, which limited the types of differentiation they used. This suggests a need for school and district officials to develop a deeper understanding of the philosophy and instructional practices associated with DI in order to support teachers in moving toward more complex differentiation strategies.

Given that only one teacher in the study employed a breadth of differentiation strategies, the recommendation for professional development to support in-service science teachers' differentiation practices continues to apply. Research indicates that effective professional development for science teachers acknowledges teachers' current beliefs and practices, is sustained and context-specific, fosters collaboration, and provides teachers with feedback (Loucks-Horsley, Stiles, & Hewson, 1996; Wayne, Yoon, Zhu, Cronen, & Garet, 2008). Based on these recommendations, ongoing, science-specific, standards-based professional development that incorporates modeling and practice teaching of differentiated lessons may be effective in developing teachers' differentiation practices. Opportunities for teachers to reflect and receive feedback on these experiences in terms of their engagement, specific instructional strategies employed, and classroom management may further support teachers' comfort in implementing DI in their own classrooms. Finally, collaborating with content-area peers to differentiate instructional activities they already use may help teachers begin differentiating instruction.

Results of the present study suggest that learning profile differentiation that accounts for students' cultural differences may be challenging for science teachers to design and implement in classrooms. Thus, both preservice science teacher preparation and professional development should emphasize planning differentiated activities and lessons that take into account these differences among students. Given the documented difficulty some students encounter in negotiating the difference between their 'everyday life-world and the world of school science' (e.g. Aikenhead & Jegede, 1999, p. 48), and the emphasis on 'science for all' in science education reforms documents (AAAS, 1993; NRC, 1996, 2011), this is of particular importance in science instruction.

Finally, DI is well-aligned with student-centered, social constructivist science instruction advocated in the Next Generation Science Standards and other reform documents (NRC, 2011; Tomlinson & Allan, 2000). Employing ongoing formative assessment to assess students' progress toward learning goals and to inform teachers' development and implementation of instructional activities to meet varied student needs is a hallmark of DI. Such an approach has the potential to help teachers meet the needs of all students, including those with various disabilities, within a reforms-based curriculum. In addition to addressing the needs of groups of students with similar needs, teachers must also address the individualized requirements of students' Individualized Education Plans (IEPs) within differentiated instructional activities. In this investigation, Diane's year-end review lesson and lesson on molarity/colligative properties represents an example of a teacher using formative assessment to design instruction to meet the varied needs of groups of students in her class; however, it does not represent how a teacher might rise to the very real, added challenge of layering DI with individualized instruction required of IEPs within today's secondary science classrooms.

The findings of the present study and prior research indicate teachers struggle to incorporate effective formative assessment practices into instruction (Daws & Singh, 1996, 1999; Doubet, 2007; Morrison & Lederman, 2003). Addressing instructional strategies, such as ongoing formative assessment, that provide a foundation for consistent, effective differentiation during science teacher preparation programs may support the development of preservice teachers' DI. Added focus on formative assessment practices during preservice science teacher preparation may help preservice teachers understand how to collect, analyze, and use information from formative assessments for the purposes of planning differentiated activities. Similar support should be provided to in-service science teachers during professional development experiences. Emphasizing effective formative assessment practices during preservice science teacher preparation and professional development may facilitate effective readiness differentiation.

Although we can learn much from these teachers' experience differentiating instruction, the exploratory nature of the study, the small sample size, and the purposeful selection of participants limits generalization of the results to other settings. Future research should explore the generalizability of these results. Internationally, stakeholders in science education want evidence that pedagogical practices of science teachers increase scientific literacy, achievement, and affect toward science among all science students. Therefore, future studies should also address student affect toward differentiated lessons and science and achievement outcomes as a result of DI. Finally, this investigation does not address professional development outcomes for in-service teachers related to DI, which would continue to build our knowledge of the field. Specifically, the results of the present study suggest a need to explore the best methods to support effective formative assessment and readiness differentiation among in-service secondary science teachers.

Disclosure statement

No potential conflict of interest was reported by the authors.

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