

Author's final pre-print version of:

Schmidt, J. A., Rosenberg, J. M., & Beymer, P. (2018). A person-in-context approach to student engagement in science: Examining learning activities and choice. *Journal of Research in Science Teaching*, 55(1), 19-43. <https://dx.doi.org/10.1002/tea.21409>

A Person-in-Context Approach to Student Engagement in Science:
Examining Learning Activities and Choice

Abstract

Science education reform efforts in the United States call for a dramatic shift in the way students are expected to engage with scientific concepts, core ideas, and practices in the classroom. This new vision of science learning demands a more complex conceptual understanding of student engagement and research models that capture both the multidimensionality and contextual specificity of student engagement in science. In a unique application of person-oriented analysis of experience sampling data, we employ cluster analysis to identify six distinct *momentary engagement profiles* representing different combinations of the behavioral, cognitive, and affective dimensions of student engagement in high school science classrooms. Students spend a majority of their classroom time in one of several engagement profiles characterized by high engagement on one dimension, but low levels on the others. Students exhibited low engagement across all three dimensions of engagement in about 22 percent of our observations. Full engagement, or high levels across all three dimensions, is the least frequent profile, occurring in only 11% of the observations. Students' momentary engagement profiles are related in meaningful ways to both the learning activity in which students are engaged and the types of choices they are afforded. Laboratory activities provided especially polarized engagement experiences, producing full engagement, universally low engagement, and pleasurable engagement in which students are affectively engaged but are not engaged cognitively or behaviorally. Student choice is generally associated with more optimal engagement profiles and the specific type of choice matters important ways. Choices about how to frame the learning activity have the most positive effects relative to other types of choices, such as choosing whom to work with or how much time to take. Results are discussed in terms of implications for practice and the utility of the methodological approach for evaluating the complexities of student engagement in science classrooms.

Keywords: science engagement, learning activities, instructional practices, choice, person-oriented analysis

Most science teachers, at any level, will tell you that one of their greatest desires is for their students to engage deeply with science content. In academic circles, student engagement has been referred to as “the holy grail of learning” (Sinatra, Heddy, & Lombardi, 2015, p.1). Indeed, the surge of research on student engagement across a number of disciplines in the past two decades is remarkable, and the range of learning outcomes associated with it is impressive. Student engagement serves as a primary framework for understanding and combating school dropout (Christenson et al., 2008; Finn & Owings, 2006) and is positively associated not only with achievement but also other self-regulatory, social, and emotional learning outcomes both in and outside of school (Klem & Connell, 2004; National Research Council and the Institute of Medicine, 2004).

While research and theory on student engagement has proliferated in the past decade, only a small number of studies have focused specifically on the domain of science. The research focused on science generally suggests low levels of student engagement in science, which declines across the schooling years (George, 2000; Gottfried, Fleming, & Gottfried, 2001; Greenfield, 1997; Osborne, Simon & Collins, 2003). Given the recent push in the United States to strengthen its workforce in the science, technology, engineering and mathematics (STEM) fields (National Academy of Engineering and National Research Council, 2014; National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2005), the engagement construct is particularly attractive, as it may play an important role in promoting skill development and persistence in science majors and careers (Sinatra et al., 2015). However, the field has not yet reached consensus on how to define or measure the engagement construct in academic settings more generally or in science in particular. Additionally, at present there is only a small body of research that examines the ways in which specific features of science learning

environments can foster the active engagement required for skill-building, achievement, and persistence in science.

To address these gaps in our understanding, the aim of this paper is two-fold. First, we explore a method of studying science engagement that captures the complexity of the engagement construct, taking into account current theory and research. Second, we examine the relationship between features of science learning environments and engagement as a first step toward identifying ways that science teachers can design their instruction to optimally engage students. Specifically, we examine how student choice and particular learning activities are related to student engagement in high school science classrooms.

Defining and Framing Student Engagement in Science

In their recent *Handbook of Research on Student Engagement*, Christensen, Reschly and Wylie (2012) offer the following definition of student engagement:

Student engagement refers to the student's active participation in academic and co-curricular or school-related activities, and commitment to educational goals and learning. Engaged students find learning meaningful, and are invested in their learning and future. It is a multidimensional construct that consists of behavioral, cognitive, and affective subtypes. Student engagement drives learning; requires energy and effort; is affected by multiple contextual influences; and can be achieved for all learners (p. 816-817).

This definition represents a synthesis of the theoretical and empirical work of dozens of engagement scholars from multiple disciplines. While scholars generally agree that engagement is a multidimensional construct that is highly influenced by context, there is considerable variation in both the *grain size* at which engagement is considered and in the number and definition of the comprising subtypes or *dimensions* (Appleton, Christenson, Kim, & Reschly,

2006; Fredricks, Blumenfeld, & Paris, 2004; Reeve, 2013; Sinatra et al., 2015). Here “grain size” refers to the level of specificity at which engagement is conceptualized and measured (e.g., engagement in school generally, in a specific content area, or in a specific learning activity, see Sinatra et al., 2015), and “dimensions” refer to the multiple aspects of engagement specified in a given conceptual framework. Reschly and Christenson (2012) have observed that the engagement field currently suffers from a “jingle-jangle” problem in that scholars use the same term (e.g. “affective engagement”) to refer to different constructs (*jingle*), and also use different terms to refer to the same construct (*jangle*). Indeed, in a review article, Azevedo (2015) observes that while current competing definitions of engagement are rooted in particular empirical and theoretical traditions, formal *theories of engagement* have not yet been articulated for academic domains more generally or for science in particular. In the absence of a shared understanding of the specific dimensions of engagement and their definition, it is crucial for researchers to clearly define the dimensions of engagement that frame their research, pointing to the theoretical and conceptual approaches with which their definitions are most closely aligned (Christenson et al., 2012; Sinatra et al., 2015). While space limitations prevent us from providing a comprehensive review of the various frameworks for engagement that have been articulated to date, we direct the interested reader to several thoughtful reviews (Appleton, Christenson, & Furlong, 2008; Christenson et al., 2012; Fredricks et al., 2004; for a review focused exclusively on science see Sinatra et al., 2015).

In keeping with the understanding that engagement is highly influenced by context, we conceptualize engagement as variable, and have chosen to study engagement in science at a relatively fine grain size, focusing on students’ momentary states while interacting with academic content. We chose this grain size rather than a broader conception of general science

engagement because it is at this level where teacher practice is likely to have the most immediate and observable impact. Engagement at this level is thought to represent the more “proximal processes” that developmental scholars argue fuel learning and development (Bronfenbrenner & Morris, 1998; Skinner & Pitzer, 2012). Engagement at this level also corresponds to *situated* views of motivation that emphasize the importance of understanding the contexts in which students’ motivated beliefs and behaviors occur (Nolen, Horn, & Ward, 2015).

Our framework of momentary engagement specifies three dimensions: behavioral, cognitive, and affective. To date, these are the most commonly identified and studied engagement dimensions (Christenson et al., 2012; Fredricks et al., 2004, Fredricks & McColskey, 2012). While there is a limited body of empirical work focused on science engagement in particular, this tripartite view of engagement often frames that literature as well (Sinatra, 2015; Vedder-Weiss, 2017). Our conceptualization of these three dimensions is framed by models of engagement articulated by Appleton et al. (2006, 2008), Fredricks et al. (2004), and Skinner et al. (2008, 2009). While the dimensions as described below represent a synthesis across these models, there are important variations between them in terms of the specific dimensions specified and how they are defined. These distinctions across these two models, and the points at which our definitions diverge from each are summarized briefly in Supplementary Material 1. Interested readers are also referred to Appleton et al. (2008) Fredricks et al (2004), Fredricks and McColskey (2012) and Reschly and Christenson (2012) for more thorough comparisons across these and other engagement models more generally and Sinatra et al. (2015) for a review focused specifically on science engagement.

Behavioral engagement. This dimension of engagement refers to one’s involvement in academic activities in terms of their participation, effort, intensity, or persistence. For example, a

high school student exhibits the behavioral dimension of momentary engagement in a laboratory experiment when she exerts the effort to complete the procedures outlined in a laboratory assignment about measuring the Ph levels of various liquids she collected, remaining focused on carrying out the task. Behavioral engagement is considered critical for academic achievement and dropout prevention (Birch & Ladd, 1997; Connell & Wellborn, 1991; Finn, 1989; Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2012; Fredricks et al., 2004, 2011). In a review of literature on science engagement, Sinatra and colleagues (2015) conclude that research has established fairly robust links between behavioral engagement and achievement across a variety of academic domains including science. However, they caution that the achievement assessments that form this evidence base largely represent low-level processing tasks that involve simple recall. They argue that behavioral engagement alone may not be the most reliable predictor of achievement in more complex tasks (like those often found in science learning) that demand higher order processing strategies, because without the addition of cognitive engagement, behavioral engagement may be insufficient.

Cognitive engagement. Cognitive engagement refers generally to the psychological and motivational investment one makes in academic activities. More specifically, the conceptual models upon which this study is based use this term to refer to the degree to which students' perceive their academic activities as valuable. The student in the Ph lab could be said to exhibit the cognitive dimension of momentary engagement if she perceives understanding Ph as valuable or important: For example she might recognize the importance of Ph levels to sustaining marine life or soil fertility. Self-regulation and strategy use are common hallmarks of cognitively engaged students (Connell & Wellborn, 1991; Finn & Zimmer, 2012; Fredricks et al., 2004, 2011; Gasiewski et al., 2012; Greene & Miller, 1996). In a review of 20 years of research on

cognitive engagement, Greene (2015) laments that we know less about the predictors and consequences of cognitive engagement in science than we do in other academic domains because research has not historically focused on science. Nonetheless, in her own work she has found that cognitive engagement in science is predictive of achievement.

Affective engagement. Affective engagement refers to the positive and negative feelings students have towards teachers, peers, learning activities, and/or the school in general (Pekrun & Linnenbrink-Garcia, 2012). These feelings may include boredom, excitement, enjoyment, and anxiety. For example, if the activities involved in the Ph lab sparked momentary interest and enjoyment in the student, she would be experiencing the affective dimension of momentary engagement. The affective dimension of engagement is believed to create a sense of belonging and influence the student's willingness to complete his or her schoolwork (Connell & Wellborn, 1991; Finn, 1989; Finn & Zimmer, 2012; Fredricks et al., 2004, 2011; Sinatra et al., 2015; Skinner & Belmont, 1993). Even though scholars have widely acknowledged the importance of affective processes in learning, research on affect in the context of science learning is scarce (Fortus, 2014; Wickman, 2006). However, recent work examining the role of emotions in science learning suggests student affect can be effectively influenced by changes in instruction (Itzek-Greulich & Vollmer, 2017), and that students who report higher levels of positive affect during learning score higher on measures of learning and conceptual change (Heddy & Sinatra, 2013; Heddy, Sinatra, Seli, Mukhopadhyay, 2014).

Relation of Engagement Dimensions to one Another

The three dimensions specified in our framework reflect the underlying belief that learning involves processes of acting (corresponding to the inclusion of the behavioral dimension), thinking (cognitive) and feeling (affective). The behavioral, cognitive, and affective

dimensions of engagement are not completely independent of one another, but can be conceptualized and operationalized as being relatively distinct from one another. Wickman and colleagues have argued that cognitive and affective components are often entwined in science learning processes (Wickman, 2006; Jakobson & Wickman, 2008). Similarly, Sinatra and colleagues (2015) highlight the value of using a multidimensional framework to understand science engagement, while urging scholars who use this lens to explicitly acknowledge that overlap likely exists among the dimensions. This view of distinct, yet interrelated dimensions undoubtedly contributes to the jingle-jangle problem we mentioned above. While it makes the study of engagement a bit messy, it is likely more consistent with how learning actually happens. The claim that the three dimensions are related yet distinct is borne out by existing empirical evidence, with multiple researchers detecting multidimensionality in the structure of engagement measures. Researchers who have assessed multiple dimensions simultaneously have consistently reported moderate correlations between the three dimensions (with correlation coefficients in the .40 - .55 range), and have found that statistical models specifying multiple engagement dimensions fit their data better than models specifying a single dimension (Appleton, 2008; Reeve & Tseng, 2011; Skinner et al., 2009). While the dimensions are not completely independent from one another, certain dimensions may be activated to a greater extent than others for certain students or in certain learning situations. Multiple researchers have discussed, for example, that it is possible for a student to be behaviorally engaged in learning without being engaged affectively and/or cognitively (Renninger & Bachrach, 2015; Sinatra et al., 2015). The various ways in which these dimensions of engagement combine in science learning has not been systematically explored. In this paper we are interested in understanding how frequently these different combinations occur in science learning, and identifying the features of learning contexts

that bring about these combinations. This type of exploration is important not only for its potential to empirically validate proposed conceptualizations of engagement within the domain of science, but also has relevance for educators, as it provides a window into student experience that could shape practice.

A Person-Oriented Approach to the Study of Engagement in Context

The conceptual and empirical work cited above underscore the need to consider multiple dimensions of engagement simultaneously. We assume, for example, that in a given science task it is possible for a student to have high behavioral engagement, but relatively low cognitive and affective engagement, meaning that she is working hard to complete the task, but does not value it or enjoy it much. In this same task, another student might exhibit relatively high cognitive engagement but lower affective and behavioral engagement, meaning that he sees the activity as important, but does not invest much effort in it and does not enjoy it. In representing these different scenarios empirically, scholars have taken one of two approaches. The first is to construct an aggregate measure of the three dimensions by, for example, creating means of multiple survey items. A drawback of this approach is that in terms of measurement, these two distinct profiles of engagement would be recorded as having the same “level” of engagement, although they are qualitatively different in ways that may impact achievement and persistence. The second approach represents these scenarios empirically by considering one of the dimensions to the exclusion of the others, or by constructing analytic models that isolate the effects of one of these three dimensions on an outcome while statistically controlling on the others. While there is certainly value to these *variable-oriented approaches*, their use to educators may be limited because they do not always accurately represent any actual student.

After all, science educators do not stand in front of a classroom of variables; they face whole people, each displaying a complex array of values, motives, and tendencies.

Recently, researchers have begun to explore *person-oriented approaches* to educational phenomena. Person-oriented approaches focus on identifying *profiles*, or naturally occurring constellations of theoretically related variables at the level of the individual (Bergman & Trost, 2006; Laursen & Hoff, 2006; Magnusson, 2003). A person-oriented approach can complement the growing body of variable-oriented research by more accurately representing the multidimensionality of engagement, suggesting which engagement patterns are prevalent during science instruction and under what conditions. Person-oriented approaches have been applied in the study of achievement goals (Jang & Liu, 2012; Wormington & Linnenbrink-Garcia, 2016), intrinsic and extrinsic motivations (Corpus & Wormington, 2014), expectancies and task values (Wormington, 2016), and school adjustment (Bergman & Trost, 2006).

In a paper that was influential in the development of the present study, Conner and Pope (2013) proposed a theoretical typology of engagement that articulates seven engagement profiles representing all possible combinations of high and low engagement in the behavioral, cognitive and affective domains (each conceptualized similarly to the present study). However, their research examining this typology was conducted at a very large grain size: The study involved administration of a one-time survey about students' general school engagement. Due to this design limitation, the authors empirically validated only a small part of their typology and could not examine engagement in particular content areas like science or in particular learning activities. Other recent studies have found evidence of distinct multidimensional profiles of student engagement using different conceptual frameworks (Salmela-Aro, Moeller, Schneider, Spicer, and Lavonen, 2016; van Rooij, Jansen, van de Grift, 2017), but again these profiles were

conceived at a larger grain size, capturing profiles of general engagement with school, rather than engagement that is specific to science to a particular learning task.

Person-oriented approaches may be particularly important and relevant for the study of science engagement. Current science reform efforts emphasize the importance of not just “going through the motions” of science through hands-on activity, but of recognizing the relevance and importance of science in everyday life, and appreciating the “wonder and beauty of science” (National Research Council, 2012, p. 1). This call for more advanced engagement in learning activities suggests the importance of attending to multiple dimensions of student engagement simultaneously (Sinatra et al., 2015; Sinatra & Chinn, 2011). Affective processes are increasingly framed as important, but are particularly understudied in the context of science learning (Fortus, 2014; Wickman, 2006): thus it is important to understand how this dimension of engagement operates in concert with the behavioral and cognitive dimensions, which are more frequently examined in science contexts. Schneider and colleagues have further argued that the current focus in science education on everyday science activities “compels us to rethink science learning as a situation specific event in which students’ learning is tied to their social and emotional states” (Schneider et al., 2016, p. 415). Using a variable oriented approach, these authors demonstrate the potential value of situational approaches to engagement by identifying a number of situational correlates what they refer to as *optimal learning moments* in science, which are defined as a combination of momentary student interest, skill, and challenge.

In the current study, we apply a person-oriented analytic framework to data on students’ momentary experiences in science learning environments gathered using the Experience Sampling Method (ESM). We use these multiple measures gathered across different science learning activities to explore students’ *momentary engagement profiles*, thus providing a detailed

exploration of the context-dependence articulated in current engagement theory. The results of this exploration provide critically important information for science educators about exactly how students engage in different types of learning environments.

Situational Affordances of Science Engagement: Learning Activity and Choice

Renninger and Bachrach (2015) argue that it is important to understand what features of science learning environments are most effective at triggering the different dimensions of engagement, citing that some situations may trigger only behavioral engagement, while others may be more effective at triggering engagement in the affective or cognitive domains. At the same time, Sinatra and colleagues (2015) have observed that the wide variety of learning activities employed in science classrooms, including laboratory and other activities designed to introduce students to scientific content, presents particular methodological challenges to researchers trying to assess student engagement in these various activities (Sinatra et al., 2015). As a first step in this effort to understand how situational factors may influence engagement on multiple dimensions we examine science learning activity and choice.

Learning activity. As “the ‘interaction partners’ with which students engage” (Skinner & Pitzer, 2012, p. 28), the learning activities students undertake in the classroom are particularly important determinants of engagement (Newmann, Wehlage & Lamborn, 1992; Skinner & Pitzer, 2012). While there will always be individual differences in the behavioral, cognitive, and affective investments students make in their academic work, students’ engagement is also attributable in part to the learning activities themselves (Kang, Windschitl, Stroupe, & Thompson, 2016). A given learning activity can be characterized as providing different affordances for cognitive, affective and behavioral engagement. For example, some learning activities may provide an opportunity for entertainment in that they are enjoyable and interesting,

but may not seem all that important to students and may not require students to work very hard. These activities might be said to provide high affordances of affective engagement, but low affordances for cognitive and behavioral engagement. Studies employing the experience sampling method have shown that the quality of students' experience in classrooms varies fairly systematically as a function of the learning activity in which they are involved (Shernoff, Knauth & Makris, 2000; Shumow & Schmidt, 2014).

Choice when learning. Just as learning activities may shape students' science engagement, so may choice. Self-Determination Theory (SDT) posits that autonomy is one of three essential needs that drive human behavior (Deci & Ryan, 1985; Ryan & Deci, 2000). Choice is one way to increase students' perceived autonomy that has garnered much attention (Assor, Kaplan, & Roth, 2002; Flowerday & Schraw, 2003; Flowerday, Schraw, & Stevens, 2004; Patall, 2013; Patall, Cooper, & Robinson, 2008; Patall, Cooper, & Wynn, 2010). Although educators tend to believe that choice in the classroom is beneficial to student learning (Flowerday & Schraw, 2000), findings are mixed regarding the effect of choice on student outcomes. In a meta-analysis of 41 studies, Patall et al. (2008), report that when students are afforded choice in learning, they demonstrate greater intrinsic motivation and effort. In multiple studies, Flowerday and colleagues found either no effects or negative effects of choice on motivational outcomes such as engagement (Flowerday & Schraw, 2003; Flowerday et al., 2004). Others suggest that whether or not choice influences engagement may depend on features of the context in which choice is offered (Assor et al., 2002; Katz & Assor, 2007; Patall, 2013).

It is conceivable that different types of choices may have different impacts on the various dimensions of engagement. For example, having the ability to choose whom one works with might affect the three dimensions of engagement differently than choices related to how to frame

a given science activity. It is important for science teachers to understand which kinds of choices are likely to yield the biggest payoff in terms of student engagement. Teachers have a number of different ways to incorporate choice into instruction, but most research on choice in the classroom has focused on one type of choice (choosing between assignments or tasks). Thus, we know very little about how specific types of choices shape student engagement. In addition, the majority of studies on choice cited above involved experimental research conducted with undergraduate students or adults, which may have limited applicability to high school students in science classrooms. In the current study, we examine the impact of a number of naturally occurring choices on high school students' momentary engagement.

Research Questions

In order to explore students' engagement patterns and the influence of learning activity and choice on these patterns, the following research questions will be addressed:

1. What types of momentary profiles characterize students' engagement in science?
2. In what ways are particular science learning activities related to students' momentary engagement profiles?
3. In what ways are student choices during instruction related to students' momentary engagement profiles?

The answer to these questions may support science teachers in making more informed decisions about instruction.

Method

Context

The study took place in a single comprehensive high school serving students from a diverse community located on the fringe of a large metropolitan area. At the time of the study,

the school enrollment was approximately 3,300 with a graduation rate of 74%. Data were collected from students and teachers in 12 regular-track science classrooms: Three classrooms each in the areas of integrated science, biology, chemistry, and physics.

Participants

Teachers. Thirteen teachers¹ in twelve classrooms participated in the study. Six of the teachers (46%) were male. As is the case in the science department as a whole, all participant teachers were white. They had an average of 8.6 years of teaching experience, and their average age was 35.6. Three teacher participants had earned National Board Certification (see Table 1).

Students. In total, 244 students participated in the study. The overall student participation rate across all classrooms was 91%. The sample was 53% male, 42% Hispanic, 37% White, 12% African American, 2% Asian, 1% Native American, and 6% multi-racial. According to school records, 43% of students in the sample were eligible to receive free or reduced lunch. Half of the students in the sample reported that neither of their parents had attained a college degree. Nineteen percent said that at least 1 parent had graduated from college, and 14% indicated that at least one parent had earned an advanced degree. Seventeen percent of students in the sample did not know their parents’ educational attainment (see Table 1).

Table 1
Participant Demographic Characteristics

Students (N = 244)	% Students	Teachers (N = 13)	# Teachers
<i>Sex</i>		<i>Sex</i>	
Male	53%	Male	6
Female	47%	Female	7
<i>Race/Ethnicity</i>		<i>Race/Ethnicity</i>	
Hispanic	42%	White	13

¹ In one of the integrated science classrooms, a new teacher was assigned to the class in the spring semester as a result of staffing changes elsewhere in the department.

ENGAGEMENT, LEARNING ACTIVITY, AND CHOICE

White	37%		
Black	12%	<i>Education Level Completed</i>	
Multi Racial	6%	Four Year College Degree	5
Asian/Pacific Islander	2%	Master's Degree	7
American Indian	1%	Ph.D., or Other Advanced Degree	1
		<i>National Board Certification</i>	3
<i>Subject</i>			# of Years
Integrated Science	20%	<i>Mean Age</i>	35.6
Biology	30%		
Chemistry	25%	<i>Mean Years of Teaching Experience</i>	8.6
Physics	25%	(range 2-19)	
		<i>Grade Level</i>	
9th	43%		
10th	21%		
11th	34%		
12th	2%		
<i>Free/Reduced Lunch</i>	43%		
		<i>Parent Education</i>	
High School or less	34%		
Some college	16%		
Graduated from	20%		
College			
Advanced Degree	15%		
Don't Know	15%		

Procedures

Within each of the 12 classrooms, data were collected over two time periods—once in fall and once in spring. In both periods, methods of data collection included experience sampling techniques and videotaping. Data from different sections of a given course were collected at the same point in the semester, and thus represent the same point in the science curriculum.

Experience sampling method. During each period of data collection, students' subjective experience in science was measured repeatedly over a period of five consecutive

school days using the Experience Sampling Method (ESM; Csikszentmihalyi & Larson, 1987). Participants wore a vibrating pager which was used to signal them unobtrusively using a remote transmitter at two randomly selected time points during each day's science class. To minimize the disruption to class flow and maximize the variety of classroom activities recorded, the pool of participants in each classroom was divided in half, with each half following a different signal schedule. In response to each signal, students completed a form in which they briefly recorded their activities and thoughts at the time of the signal, as well as various dimensions of their subjective experience. This took approximately one to two minutes to complete.

Using rating scales, students reported on multiple dimensions of their subjective experience. By the study's completion, each participant had reported on multiple aspects of subjective experience on as many as 20 separate occasions with each descriptive array linked to a specific course and classroom activity. In total, 4,136 such responses were collected. The response rate to the ESM signals was 91%. Participant non-response to the ESM was nearly entirely attributable to school absence.

Video data. During the five days of ESM signaling in both fall and spring, a videographer was positioned in each classroom to unobtrusively record classroom activities. Using the NVivo software package, the video data were coded to characterize the nature of classroom activity from the beginning to the end of each class session, such that each class period was broken down into a series of time segments representing discrete activities. For example, in a given 50 minute class period, the first 6 minutes may have been coded as "non-instructional time" to reflect that the teacher used this time to remind students of the schedule of activities and due dates in the days and weeks ahead. The 9 minutes following this in which the teacher introduces concepts and ideas relevant to the day's activity would be coded as "lecture."

This might be followed by 27 minutes in which students participated in a hands-on activity in which they explored the concepts and ideas from the lecture by collecting and analyzing data (coded as “laboratory”), and then 8 minutes of “individual seatwork” not directly related to the lab. Following criteria used by Duke (2000), in instances where multiple discrete activities occurred simultaneously (e.g. a handful of students have begun their independent seat work while most students are working on a lab), the video segments were coded according to what the majority of students were doing. Video footage was marked to indicate exactly when all ESM signals were emitted in order to identify the learning activities in which students’ subjective ratings occurred. Note that ESM signals were intentionally not emitted during transitional periods between one activity and another so that ESM responses could be clearly linked to a single activity. All classroom activities were categorized using one of ten codes to indicate the learning activity in which students were involved using criteria drawn from Duke (2000), Barak and Shakhman (2008), Their and Daviss, 2002, and Von Secker and Lissitz (1999). Inter-rater reliability was high (96%; disagreements were resolved through discussion). The activity codes, and a brief operational definition of each are provided below.

Lecture. Large-group instruction in which a teacher explains concepts, ideas, and/or presents facts about science. May include occasional questioning of students or brief demonstrations.

Individual work. Students work independently on seat work (not laboratory work – see below) under teacher guidance. Examples include homework, warm-up problems, silent reading and video/computer simulations in which students solve problems based on what is presented visually. Teacher may monitor and scaffold student progress.

Laboratory. Activities involving planning an investigation, observing, collecting observations and constructing measures, analyzing data, and/or interpreting results and making predictions. Includes immediate preparation for and subsequent discussion of these activities.

Tests and quizzes. Formal assessment of student knowledge/performance on particular science topic(s). Is typically identified by teachers and/or students as a test or quiz.

Discussion. Dialogue between multiple class members (typically teacher led though students assume some responsibility for direction of conversation). Involves open-ended questioning, prioritizing expression of students' explanations before teacher's, presentation of diverse viewpoints around a particular issue.

Video. Students watch video related to a science topic. May include showing video of laboratory experiments.

Group work. Defined similarly to individual work above, only the work is completed in pairs or small groups rather than independently.

Presentation. Students share their ideas and conclusions about a science topic with the class in a formal way that reflects advance preparation.

Non-instructional activity. Anything course-related but not content related. Includes presentation of advance organizers (outlining activities for the day or the week), announcements about changes in class schedule or routine, distributing materials.

Other. Activities unrelated to science. Examples include the pledge of allegiance, discussing weekend activities, sports, or current events.

Measures

Measures of engagement. Three measures of engagement were constructed by taking means of items from the ESM, each on a zero (not at all) to three (very much) scale. A measure

of *behavioral engagement* was computed by taking the mean of student responses to the questions “How hard were you working?” and “How well were you concentrating?” *Cognitive engagement* was measured as the mean of students’ ratings on the questions “How important was what you were doing do you?” and “How important was it to your future?” *Affective engagement* was computed as the mean of students’ ratings on the questions “Was this activity interesting?” and “Did you enjoy what you were doing?” These items have been used extensively in prior research (see Hektner, Schmidt & Csikszentmihalyi, 2007 for a review), and the composite measures are consistent with prior research efforts to measure behavioral, cognitive, and affective engagement using a person-oriented approach (Conner & Pope, 2013).

Choice. Each time students were signaled, they were asked to indicate whether or not they had choice in the activity they were doing at the moment. When they had choice, they indicated whether or not they chose: 1) who to work with; 2) what materials to use; 3) how much time to spend; 4) how to do the activity; 5) which activity to do; 6) the topic; 7) how to define the problem; and 8) an “other choice.” Students could check as many choice options as applied each time they were signaled. In analysis, the activity, topic and defining the problem choice options were collapsed into a single category that we call “framing.” These three choice options were chosen infrequently relative to other choices, are conceptually similar, and showed similar relationships with the variables of interest to this paper. Thus, in our analysis, we examined five different choice options against the option of no choice.

Data Analysis

Drawing from Bergman and El-Khoury’s (1999) and others’ (e.g., Corpus & Wormington, 2014) approach to person-centered analyses, we used a two-step cluster analysis to identify profiles of momentary engagement using the three engagement measures. All measures

were grand mean scaled ($M = 0$, $SD = 1$). Analyses were conducted using the statistical software and programming language R (R Core Team, 2016)². The first step employed hierarchical clustering in which observations are grouped together on the basis of their similarity³ hierarchically, so that in subsequent steps similar clusters of observations are merged together⁴ until a specified number of clusters has been reached. While hierarchical cluster analysis has many benefits (such as reaching the same solution each time; Hastie, Tibshirani, & Friedman, 2009), it may yield solutions that are not optimized in terms of the ratio of within to between cluster variance. As a result, k-means cluster analysis is commonly used following hierarchical cluster analysis. In k-means cluster analysis, observations are assigned to the cluster with the mean values on the clustering variables most similar to its own in an iterative process, using the assignments from the hierarchical analysis as “starting points” (Hastie, Tibshirani & Friedman, 2009). This two-step process takes advantage of the replicability of the hierarchical analysis and the optimization of the k-means analysis, together addressing the limitations of each (Bergman & El-Khoury, 1999; Corpus & Wormington, 2014).

To test whether momentary engagement profiles varied as a function of learning activity and choice, we examined the distribution the identified profiles across activity and choice using chi-square and multiple logistic regression procedures. Our initial analyses examined content area (integrated science, biology, chemistry, physics) but this information did not meaningfully explain relationships in the momentary measures examined here. Thus in the interest of parsimony content area is not included in analyses.

Results

² We developed an R “package” (freely available to other researchers) to facilitate the data analysis (Rosenberg, Schmidt & Beymer, 2017)

³ Based on the squared Euclidean distance between observations.

⁴ Using complete linkage, which merges clusters on the basis of the shortest distance between any observations within clusters.

Preliminary Analysis

Means, standard deviations, and indicators of internal consistency for the engagement measures are as follows: Behavioral, $M = 2.92$, $SD = .88$, $\alpha = .80$; cognitive, $M = 2.14$, $SD = .91$, $\alpha = .80$; affective, $M = 2.26$, $SD = .87$, $\alpha = .75$. Internal consistencies for all measures are reasonable given the small number of items used. Correlations indicate, as theory suggests, that the dimensions of engagement are related, but distinct: $r_{behavioral-cognitive} = .46$ ($p < .001$); $r_{behavioral-affective} = .54$ ($p < .001$); $r_{cognitive-affective} = .47$ ($p < .001$).

The learning activity that occurred most often during the randomly administered ESM signals was laboratory activity (25%), followed by quizzes and tests (17%), individual work (16%), and lecture (13%). Other activities in which ESM signaling took place included discussion, videos, group work, presentation, non-instructional activities, and “other,” but each of these activities accounted for fewer than 10% of ESM responses, so were not included in our examination of learning activities. For a full accounting of learning activities the reader is referred to Supplementary Material 2.

Students reported having choice in framing the activity in 19% of all ESM responses. Other choices included how much time to spend (12%), who to work with (9%), how to complete a given assignment (16%), which materials to use (11%) and “other” choices (13%). These choices often co-occurred. In total, students reported having choice about one or more aspects of their learning activities in 55% of the ESM reports gathered, and reported no choice whatsoever in 45% of the cases (see Supplementary Material 2).

Identifying Momentary Engagement Profiles (MEPs)

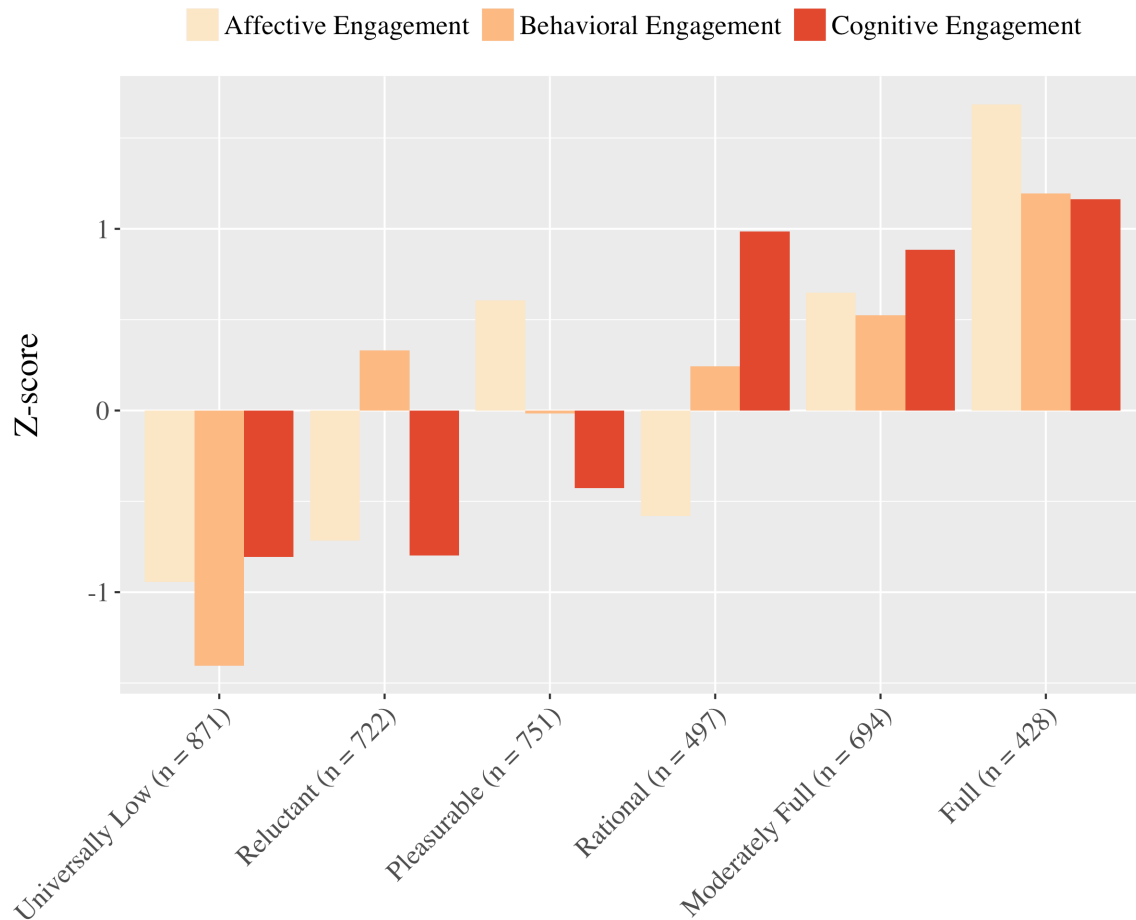
Of the 4,136 ESM responses collected, 141 cases (3%) were removed from the cluster analyses because they were missing data for one or more of the engagement measures. 32

multivariate outliers were removed, resulting in a final data set of 3,963 ESM responses. On the basis of multiple fit indices, cross-validation, and concerns of interpretability and parsimony, a six-cluster solution was chosen. This solution explained 66% of the variance in behavioral engagement, 70% of the variance in cognitive engagement, 78% of the variance in affective engagement, and 72% of the total variance (above 50% is typically viewed as acceptable in studies of this type; see Corpus & Wormington, 2014). A double-split cross validation procedure using randomly selected halves (Breckenridge, 1989), replicated 30 times, confirmed that this solution was stable ($\kappa = .72$). The cross-validated agreement ($k = 30$) was .76. The six-cluster solution represented the best combination of cross validation percentage with proportion of explained variance. This solution was further validated using a multivariate analysis of variance (MANOVA), which confirmed that cluster centroids were significantly different from one another across clusters.

The six clusters in the final solution represented theoretically meaningful combinations of the three engagement dimensions, and are largely consistent with the theoretical taxonomy of engagement proposed by Conner and Pope (2013). Thus, the terminology proposed in this taxonomy is used whenever possible in referring to the clusters identified in our analysis. We refer to these clusters as Momentary Engagement Profiles (MEPs). The final solution included a *universally low* MEP, which represented low levels of all three engagement dimensions ($n = 871$), a *reluctant* MEP, representing moderate levels of behavioral engagement and low levels of affective and cognitive engagement ($n = 722$), and a *rational* MEP, representing high cognitive engagement and lower behavioral and affective engagement ($n = 497$). The analysis identified a *pleasurable* MEP, characterized by higher levels of affective engagement paired with lower levels of behavioral and cognitive engagement ($n = 751$), in addition to a MEP representing

moderately full engagement with moderately high levels of all 3 engagement dimensions ($n = 694$) and one representing *full engagement*, with high engagement on all three dimensions ($n = 428$). Figure 1 presents standardized means on the three engagement dimensions for each cluster.

Figure 1
Momentary Engagement Profiles (MEPs)



Cluster centroids are significantly different from one another as assessed using a multivariate analysis of variance (MANOVA).

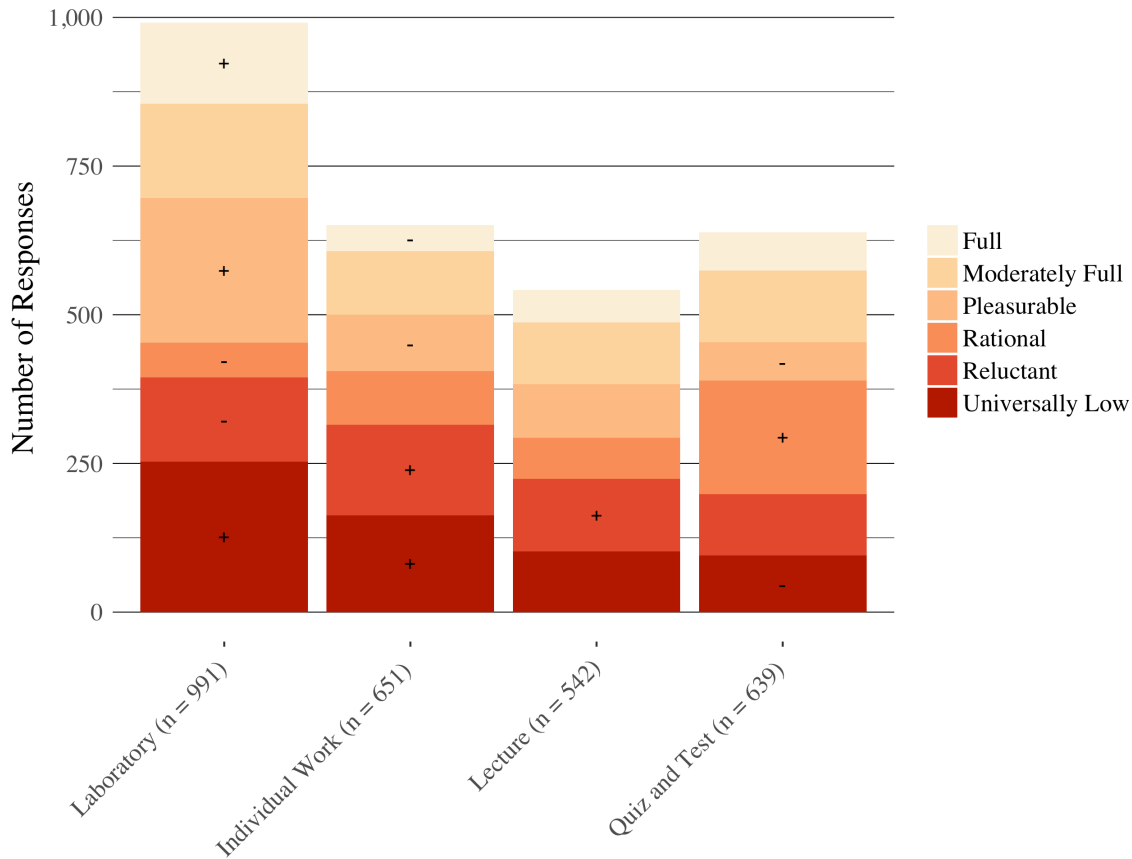
Associations between Learning Activity and Students' Momentary Engagement

A Chi-square test for independence indicated that there was a significant association between the learning activity in which students were engaged and their MEP, $\chi^2 = 339.16$, (20, $p < .001$), Cramer's $V = .18$, a medium effect size. Distributions of the MEPs within the four most common learning activities are displayed in Figure 2, and standardized residuals for this analysis

are presented in the Supplementary Material 3. Importantly, laboratory activities elicit the extremes in terms of engagement: Students exhibit both full engagement and universally low engagement more frequently than expected when they are doing labs, whereas reluctant and rational engagement was observed less often. Students experienced much more frequent pleasurable engagement in labs relative to other learning activities. During individual work, students were more likely to report universally low engagement and reluctant engagement, whereas they were less likely to report full engagement and pleasurable engagement. Students were more likely to exhibit reluctant engagement when listening to lecture. When taking tests and quizzes, students were less likely to report universally low engagement or pleasurable engagement, but were more likely to report rational engagement, meaning that they recognized the activity as important, but displayed average levels of hard work, and didn't enjoy the task.

Figure 2.

Distribution of Momentary Engagement Profiles by Learning Activity



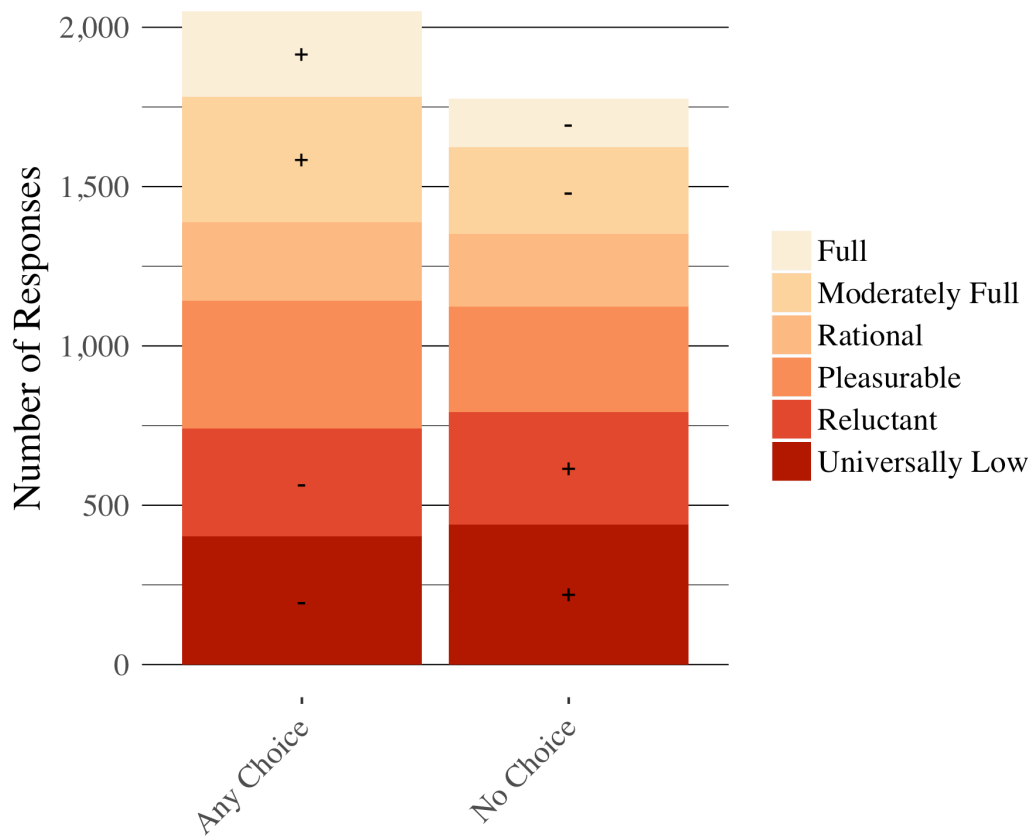
Note. $\chi^2 = 339.16$ (20, $p < .001$), $\phi: .18$ (medium effect size). Standardized residuals are presented in Supplementary Material 3.

+ or - indicates a standardized residual with an absolute value greater than 1.96.

Associations between Choice and Students' Momentary Engagement

A Chi-square test for independence indicated a significant association between choice and students' MEP, $\chi^2 = 43.269$ (5, $p < .001$), $\phi = .11$, a small effect size. When students are afforded choice of any kind, they are more likely to be fully engaged, and less likely to report universally low or reluctant engagement compared with situations when they have no choice. Distributions of MEPs within the choice and no-choice conditions are presented in Figure 3, and standardized residuals from this analysis are reported in Supplementary Material 4.

Figure 3
Distribution of Momentary Engagement Profiles by Choice



Note. $\chi^2 = 42.269$ (5, $p < .001$), Cramer's V: .11 (small effect size). Standardized residuals are presented in Supplementary Material 4.

+ or - indicates a standardized residual with an absolute value greater than 1.96.

In order to examine the relationship of specific types of choices with engagement, we conducted a series of logistic regressions predicting the likelihood of each momentary engagement profile, given the choices afforded students at a given moment. By including as predictors all of the potential choices, the models in effect control for the presence of multiple choice options, and the regression coefficient can be interpreted as the independent effect of each choice relative to not having that particular choice. For ease of interpretation we converted log-odds coefficients to relative odds in the models summarized in Table 2. Controlling on other choices, when students are able to choose who they work with, they are about 1.4 times more likely to experience universally low engagement relative to times when they could not choose their work partner ($p < .001$). They are also one-third as likely to be rationally engaged relative

to when they do not have this choice (relative odds = .35, $p < .001$). When students choose materials, they are more likely to report pleasurable engagement (1.36, $p < .05$) and moderately full engagement (1.54, $p < .01$), and less likely to report universally low (.37, $p < .001$) or reluctant engagement. (.37, $p < .001$). Choice of time is associated with increased odds of rational engagement (1.82, $p < .001$) and decreased odds of universally low engagement (.38, $p < .001$). When students choose how to complete a course activity, they are more likely to be fully engaged relative to when they don't have this choice (1.3, $p < .05$). When students have choice about how to frame their learning activities, they are 1.6 times as likely to be fully engaged ($p < .001$), and less than half as likely to report universally low engagement (.43, $p < .05$).

Table 2
Logistic Regressions with Choice as Predicting Momentary Engagement Profiles

	Universally Low	Reluctant	Pleasurable	Rational	Moderately Full	Full
(Intercept)	.25	.20	.18	.12	.16	.09
Who	1.43 ***	1.19	1.00	.35 ***	.44 +	1.20
Materials	.38 ***	.38 ***	1.36 *	1.14	1.54 **	1.15
Time	.38 ***	.47	.49	1.82 ***	1.26 +	.47
How to Do	.45 +	1.07	.48	.46	1.14	1.35 *
Framing	.44 *	.46	.48	1.14	1.06	1.60 ***
Other	.49	.40 ***	1.24 *	.45	.12 +	1.27

Note. Columns correspond to the dependent variables, and rows correspond to coefficient estimates. Coefficients are reported as odds. The reference category for all predictors is “no choice.” Framing includes defining the problem, doing this particular activity, and the topic. + $p < .10$ * $p < .05$, ** $p < .01$, *** $p < .001$

Post-hoc Analyses: Choices in Laboratory Activities

Labs were the most frequently observed learning activity and they also appeared to be the most polarizing in that students experienced high rates of full engagement and universally low

engagement. To explore whether choice within labs helped explain some of this polarization, we conducted a post-hoc analysis using log-linear models. To streamline the interpretation, we dichotomized the choice data (creating variables to compare any choice with no choice) and examined the distribution of MEPs by choice within each learning activity. The Chi-square test indicated a significant relationship between these three variables, $\chi^2 = 357.718$ (38, $p < .001$). Standardized residuals from this analysis suggest that choice may moderate the relationship between learning activity and engagement (see Supplementary Material 5). When students report having any choice in laboratory activities, they are more likely to report full engagement ($z = 3.90$, $p < .05$), whereas this is not the case when they report no choice ($z = -.23$, *ns*). Within the other learning activities examined, choice does not increase the likelihood of full engagement as it does in lab. Conversely, when students report having no choice in lab, they are more likely to report universally low engagement ($z = 1.96$, $p = .05$) whereas this is not the case when they had choice in labs ($z = 1.61$, *ns*). Again, we see that within the other activities lack of choice does not increase the likelihood of universally low engagement. Thus, the effect of choice on full engagement and universally low engagement appears most consistently in laboratory activities rather than in other learning activities. Results also indicate that the increased likelihood of pleasurable engagement observed during labs is principally explainable by choice ($z = 5.38$, $p < .05$ for choice, $z = 1.38$, *ns* for no-choice).

Discussion

In this descriptive, exploratory study, we took a unique, person-oriented approach to studying high school students' momentary engagement in science classrooms. We set out to determine what types of momentary engagement profiles emerge in science, and then examined whether these profiles were meaningfully related to features of the learning context such as the

learning activity in which students were engaged and the types of choices they had. Cluster analysis of ESM data provides empirical evidence of the multidimensionality of science engagement, suggesting six distinct profiles representing various combinations of engagement in the behavioral, cognitive, and affective domains. Results demonstrate the situation-specificity of science engagement, showing that engagement patterns vary by both learning activity and choice. The study's findings provide important and foundational information for researchers and science educators about the different ways students engage in science learning and the instructional features that influence their engagement.

The Nature of Students' Momentary Engagement in Science

The six-cluster solution suggested by the cluster analysis indicates highly varied patterns of student engagement, and illustrates the complexity of the engagement construct in science. It is noteworthy that the most frequently observed momentary profile was universally low engagement, while the least frequent profile was full engagement, which occurred only half as often. Using momentary data, this finding confirms reports using other methods that point to low levels of student engagement in science (George, 2000; Gottfried, Fleming, & Gottfried, 2001; Greenfield, 1997; Osborne, Simon, & Collins, 2003), and underscores the need for more engaging science instruction. The prevalence of reluctant, rational, and pleasurable engagement profiles suggest some of the tensions that students may experience in their science learning, and by extension, some of the challenges science teachers may face in facilitating full engagement among their students. For example, the rational engagement profile indicates that students frequently recognize the value of the learning activity they are involved in, yet they do not enjoy it, and invest only moderate effort in the activity. In other situations, however, students substantially enjoy their classroom activities but see them as having little value, again investing

only moderate effort, as represented by the pleasurable engagement profile. Finally, students are often reluctantly engaged in science, meaning that they put forth moderate effort, but see little enjoyment or value in their work.

Looking across the engagement patterns identified in the present study, it is apparent that behavioral engagement is only high when both cognitive and affective engagement are also high, as in the case of full and moderately full engagement. This suggests that students are unlikely to exert a high degree of behavioral engagement during science learning tasks if they do not also engage deeply with the content affectively and cognitively. The simultaneous experience of high cognitive and affective engagement may be necessary—though perhaps not sufficient—conditions for high behavioral engagement. While our data do not allow us to test this conjecture empirically, the explanation has face validity: Why would someone work hard at something that was not important to her and she didn't enjoy doing? This finding suggests that in addition to providing students with learning tasks that demand concentration and effort, it is critically important for science teachers to support students' perceptions of relevance or importance, as well as students' interest and enjoyment of learning activities. The profiles identified through this analysis lend quantitative support to arguments made by scholars of science education that both cognitive and affective processes are salient features of science learning, and should be attended to in instruction (Fortus, 2014; Itzek-Greulich & Vollmer, 2017; Wickman, 2006). The present study provides a unique, fine-grained description of how these various processes combine in real time while students are doing science. Importantly, the fact that the analysis yielded consistent and replicable profiles provides strong empirical support that the general conception of science engagement as multidimensional, varying, and context sensitive accurately reflects students' actual experience in science learning environments. Moreover, the specific profiles that were

identified partially validate the typology of engagement that was proposed by Conner and Pope (2013), but has not been validated empirically.

While science educators could certainly benefit from the knowledge that their students engage in their learning in complex ways, such knowledge may have greater impact on practice if it were complimented with information about the conditions under which particular profiles of engagement were likely to occur. This speaks to the notion that certain learning conditions in science will be more likely to trigger engagement in particular domains (Renninger & Bachrach, 2015). It is useful for educators to understand these conditions as they represent concrete ways they might be able to influence their students' engagement in science. It is to this topic that we now turn.

Science Learning Activities and Engagement

Understanding students' engagement tendencies in specific learning activities helps to identify some of the barriers to full engagement that science teachers can address more explicitly in their instruction. This knowledge can be extremely valuable for teachers in their lesson planning as they contemplate how to frame and scaffold particular learning activities. The connections between specific learning activities and particular engagement profiles that are suggested by our exploratory analysis are consistent with other work suggesting that different science learning tasks may have differential effects on the affective and cognitive dimensions of experience (Iztek-Greulich & Vollmer, 2017). By and large, individual work and listening to lectures in science do not tend to engage students in optimal ways: Rather, students tend to exhibit universally low and/or reluctant engagement in these activities. The momentary engagement profiles that occur during quizzes and tests are not surprising: Students are relatively unlikely to exhibit universally low or pleasurable engagement, and instead tend to exhibit

rational engagement, meaning that they recognize high importance of the test and engage behaviorally to some extent, but do not derive interest or enjoyment from the experience. Our post-hoc analysis examining choice within these learning activities suggests that offering students choices within these activities does not make students more likely to fully engage in them, though it does decrease their likelihood of universally low engagement.

Laboratory activities stand out as having great potential to foster optimal engagement, but as often failing to live up to this potential. When students do labs, they are either fully engaged, not engaged at all, or are pleurably engaged—experiencing interest and enjoyment without putting forth much effort or recognizing the activity’s importance. This pattern of engagement characterizes all that is good and all that is bad about labs: Though labs can and do fully engage students, they are often presented as recipe-style activities where students are simply following a series of steps to produce a predetermined set of results (Kang et al., 2016). Labs often provide some “entertainment value” to students, either by demonstrating a novel phenomenon or by providing the opportunity to socialize with peers; but in these situations students do not see the activity as important or as requiring the investment of effort. A wide body of research indicates that although science instruction typically includes hands-on and experiential activities, these activities tend to be procedural, undemanding, and largely disconnected from substantive science ideas (Banilower et al., 2013; Roth & Garnier 2006; Roth et al., 2011). In a multiple case study, Kang et al. (2016) described most of the lab activity they observed as the low-demanding, disconnected variety, but note that when teachers planned tasks to be demanding, and maintained this level of rigor through the launch and implementation of the task, students were more engaged. Importantly, they also argued that framing learning activities as a means of solving questions that matter to students or as a way to understand complex

phenomena may be essential for engagement in scientific practices. Using a qualitative approach this study complements our results in that it highlights the need for teachers to support the cognitive, affective, and behavioral dimensions of student engagement in instruction.

Our post-hoc exploration of choice within learning activities provides additional explanation of the polarized engagement patterns observed in laboratory activities. These analyses suggest that students more often displayed universally low engagement in labs if the lab activity did not involve any choice, but when choice was involved, students were more frequently fully engaged. These results also suggest that teachers take caution when allowing choice in laboratory activities, as choice may also promote pleasurable engagement. It appears that some types of choices (or perhaps choices in the absence of lab activity that challenges students) may lead to an entertaining learning experience that doesn't demand cognitive or behavioral investment. Digging deeper into nature of situations in which choices are offered is beyond the scope of the present study, but future research should replicate this work while also taking into account some objective account of the demands placed on students by the lab activity.

The Power of Choice in Fostering Science Engagement

This study expands our understanding about how choice in classroom effects engagement, identifying differences between certain types of choices. This knowledge is especially helpful to science teachers as it suggests which types of choices are most likely to yield more desirable engagement patterns. Relative to students' ability to make no choice, we find that choices in general are positively associated with science engagement, particularly in laboratory activities. But our results further suggest that the type of choice matters. In particular, choices around framing (e.g., choosing the topic, the task, or how to define the problem) seem to have the most positive impact on momentary engagement in science: students are more likely to

be fully engaged and less likely to exhibit universally low engagement when they have choice in framing. This finding is consistent with research that suggests how students frame “what’s going on” in a particular science learning activity can shape knowledge construction (Stroupe, 2014) and the development of scientific argumentation—a core scientific practice (Berland & Hammer, 2012; Berland et al., 2016).

Kang et al. (2016), emphasize the importance of students and teachers co-generating the frames with which scientific tasks are understood. Arguably, providing students with the choice to define problems and tasks is an important component to this process of co-generation. While it is true that students are constantly framing their learning activities, constructing internal explanation of “what’s going on” regardless of whether they have choices, perceiving oneself as having an active role in determining the topic, task, or how the problem is defined may help students frame science learning activities in ways that promote fuller engagement. In their examination of discourse in science classrooms, Jin, Wei, Duan, Guo and Wang (2016) conclude that science teachers generally recognize that it is important to encourage students to take a more active role in their learning, but that they may need to develop more effective strategies for helping their students achieve this goal. Our results suggest that structuring activities so that students have choices about framing the activities might be one effective strategy.

In addition to the importance of framing, having choice of materials, time use, and how to do activities also seems to yield generally positive payoffs in terms of engagement, though slightly less consistently than framing choices. Choosing who to work with—a common choice offered in high school classrooms—does not provide the same affordances for engagement as most other choices examined here. When students choose whom to work with they are more

likely to exhibit universally low engagement and significantly less likely to have moderately full engagement.

We should note that our indicators of choice are subjective, representing students' perception that they had choice regarding whom to work with, how to frame the activity, and the like. These perceptions may not always align with teachers' intention to provide choice or external observers' assessments of the affordances of a given situation. Self-Determination Theory, which posits autonomy as a basic human need that is associated with positive motivational and educational outcomes, suggests that it is the perception of autonomous action rather than any objective indicator of autonomy that is most influential in producing these positive outcomes (Deci & Ryan, 1985). An interesting question for future research is how closely teacher perceptions of providing choice align with students' perception of having choice.

Limitations

This investigation is limited in several respects. First, while our analysis includes a large number of “snapshots” of student experience in science, these snapshots represent the experience of 244 students in one high school. While the data set provides an incredibly rich account of the experience of a racially, ethnically, and socioeconomically diverse group of students enrolled in a number of different scientific courses, future research should attempt to replicate our findings with different groups of students in a broader variety of science courses. Second, this study only examined two facets of learning environments—learning activity and choice. There are other facets of learning environments that can and should be investigated in future research, including more nuanced evaluation of the quality of instruction during the observed activities. Third, readers should be reminded that effect sizes for the associations between learning activity, choice, and engagement were small to moderate. Given the fine grain size at which these

phenomena were measured, larger effects are not necessarily expected, though it is possible that over time, small shifts in students' momentary engagement could arguably result in more substantial longer-term effects. Such recursive downstream effects should be examined in future studies. Finally, our study is limited in that, as a preliminary descriptive account of students' momentary engagement, it does not attempt to link momentary engagement profiles to student-level characteristics and outcomes. Because no research that we are aware of has attempted to understand engagement using the person-in-context approach used in this study, we focused our efforts on determining whether there are identifiable profiles of students' momentary engagement and if these profiles are related in any consistent way with proximal features of the learning environment like activity and choice. Given the promise of these profiles for representing science engagement in useful and nuanced ways, future research should examine the variation in momentary engagement profiles that occurs within persons, and the association of these within-person patterns with a number of educational outcomes.

Conclusion

As an investigation of momentary science engagement, this study makes several contributions to our understanding of science teaching and learning. First, our investigation describes the wide variety of engagement patterns that students demonstrate in science using data collected in real time in science classrooms: This foundational information offers empirical validation for existing conceptual definitions, focusing on the domain of science. Second, results show that these engagement patterns are related to science learning activities. Laboratory activities in particular seem to influence student engagement a great deal, in both positive and negative ways. Third, our study demonstrates that student choice matters in general, and that particular choices—such as those around framing the task—have more positive impacts on

engagement than others like choosing who to work with or how much time to take to complete a task. Framing choices emerge as facilitating full engagement in science learning activities, which aligns with the shift to position science learners as active agents in deciding critical components of learning tasks. Together, the study's results may support science teachers in making more informed decisions about instruction. Finally, the study represents a methodological advancement in the study of science engagement. The application of a person-oriented analytic approach to data that were collected *in situ* allows for the representation of science engagement as both multidimensional and contextually bound. Establishing the utility of this analytic approach in the current study opens up the possibility for linking engagement profiles to countless situation-specific aspects of learning environments. The method employed here shows promise for future investigations of the complex nature of science engagement.

References

- Appleton, J. J., Christenson, S. L., Kim, D., & Reschly, A. L. (2006). Measuring cognitive and psychological engagement: Validation of the student engagement instrument. *Journal of School Psychology, 44*(5), 427-445. doi:10.1016/j.jsp.2006.04.002
- Appleton, J. J., Christenson, S. L., & Furlong, M. J. (2008). Student engagement with school: Critical conceptual and methodological issues of the construct. *Psychology in the Schools, 45*(5), 369-386. doi:10.1002/pits.20303
- Assor, A., Kaplan, H. and Roth, G. (2002). Choice is good, but relevance is excellent: Autonomy-enhancing and suppressing teacher behaviours predicting students' engagement in schoolwork. *The British Journal of Educational Psychology, 72*(2), 261-278. doi:10.1348/000709902158883
- Azevedo, R. (2015). Defining and measuring engagement and learning in science: Conceptual, theoretical, methodological, and analytical issues. *Educational Psychologist, 50*(1), 84-94. doi:10.1080/00461520.2015.1004069
- Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). The report of the 2012 national survey of science and mathematics education. Chapel Hill, NC: Horizon Research, Inc.
- Barak, M., & Shakhman, L. (2008). Reform-based science teaching: Teachers' instructional practices and conceptions. *EURASIA Journal of Mathematics, Science & Technology Education, 4*(1), 11-20.
- Bergman, L. R., & El-Khoury, B. M. (1999). Studying individual patterns of development using I-states as objects analysis (ISOA). *Biometrical Journal, 41*(6), 753-770. doi:10.1002/(SICI)1521-4036(199910)41:6<753::AID-BIMJ753>3.0.CO;2-K
- Bergman, L. R., & Trost, K. (2006). The person-oriented versus the variable-oriented approach: Are they complementary, opposites, or exploring different worlds. *Merrill-Palmer Quarterly, 52*, 601-632. doi:10.1353/mpq.2006.0023
- Berland, L. K., & Hammer, D. (2012). Framing for scientific argumentation. *Journal of Research in Science Teaching, 49*(1), 68-94. doi:10.1002/tea.20446
- Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching, 53*(7), 1082-1112. doi:10.1002/tea.21257
- Birch, S. H., & Ladd, G. W. (1997). The teacher-child relationship and children's early school adjustment. *Journal of School Psychology, 35*(1), 61-79. doi:10.1016/S0022-4405(96)00029-5
- Breckenridge, J. N. (1989). Replicating cluster analysis: Method, consistency, and validity. *Multivariate Behavioral Research, 24*(2), 147-161. doi:10.1207/s15327906mbr2402_1
- Bronfenbrenner U., & Morris, P. A. (1998). The ecology of developmental processes. In R. M. Lerner (Ed.), *Handbook of Child Psychology* (5th ed., Vol. 1, pp. 993-1028). New York: Wiley.
- Christenson, S. L., Reschly, A. L., Appleton, J. J., Berman, S., Spanjers, D., & Varro, P. (2008). Best practices in fostering student engagement. In A. Thomas & J. Grimes (Eds.), *Best practices in school psychology* (5th ed., pp. 1099-1119). Bethesda, MD: National Association of School Psychologists.
- Christenson, S. L., Reschly, A. L., & Wylie, C. (2012). *The handbook of research on student engagement*. New York: Springer Science.

- Connell, J. P., & Wellborn, J. G. (1991). Competence, autonomy, and relatedness: A motivational model of self-system processes. *Minnesota Symposia on Child Psychology*, 23, 43–77.
- Conner, J. O., & Pope, D. C. (2013). Not just robo-students: Why full engagement matters and how schools can promote it. *Journal of Youth and Adolescence*, 42(9), 1426-1442. doi:10.1007/s10964-013-9948-y
- Corpus, J. H., & Wormington, S. V. (2014). Profiles of intrinsic and extrinsic motivations in elementary school: A longitudinal analysis. *Journal of Experimental Education*, 82, 480-501. doi:10.1080/00220973.2013.876225
- Csikszentmihalyi, M., & Larson, R. (1987). Validity and reliability of the experience-sampling method. *The Journal of Nervous and Mental Disease*, 175(9), 526-536. doi:10.1097/00005053-198709000-00004
- Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. New York: Plenum Press.
- Duke, N. K. (2000). 3.6 minutes per day: The scarcity of informational texts in first grade. *Reading Research Quarterly*, 35(2), 202-224. doi:10.1598/RRQ.35.2.1
- Finn, J. D. (1989). Withdrawing from school. *Review of Educational Research*, 59(2), 117-142. doi:10.2307/1170412
- Finn, J. D., & Owings, J. (2006). *The adult lives of at-risk students: The roles of attainment and engagement in high school*. Statistical analysis report. NCES 2006-328. U.S. Department of Education, Washington, DC.
- Finn, J. D., & Zimmer, K. (2012). Student engagement: What is it? Why does it matter? In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 97–132). New York, NY: Springer.
- Flowerday, T., & Schraw, G. (2000). Teacher beliefs about instructional choice: A phenomenological study. *Journal of Educational Psychology*, 92(4), 634-645. doi:10.1037//0022-0663.92.4.634
- Flowerday, T., & Schraw, G. (2003). Effect of choice on cognitive and affective engagement. *The Journal of Educational Research*, 96(4), 207-215. doi:10.1080/00220670309598810
- Flowerday, T., Schraw, G., & Stevens, J. (2004). The role of choice and interest in reader engagement. *The Journal of Experimental Education*, 72(2), 93–114. doi:10.3200/JEXE.72.2.93-114
- Fortus, D. (2014). Attending to affect. *Journal of Research in Science Teaching*, 51(7), 821-835. doi:10.1002/tea.21155
- Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, 74(1), 59-109. doi:10.3102/00346543074001059
- Fredricks, J. A., & McColskey, W. (2012). The measurement of student engagement: A comparative analysis of various methods and student self-report instruments. In S.L. Christenson, A. L. Reschly, & C. Wylie (2012). *The handbook of research on student engagement* (pp. 763-782). New York: Springer Science. doi:10.1007/978-1-4614-2018-7_37
- Fredricks, J., McColskey, W., Meli, J., Mordica, J., Montrosse, B., & Mooney, K. (2011). *Measuring student engagement in upper elementary through high school: A description of 21 instruments* (Issues & Answers Report, REL 2011–No. 098). Washington, DC:

- Regional Educational Laboratory Southeast, National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education.
- Gasiewski, J. A., Eagan, M. K., Garcia, G. A., Hurtado, S., & Chang, M. J. (2012). From gatekeeping to engagement: A multicontextual, mixed method study of student academic engagement in introductory STEM courses. *Research in Higher Education*, 53(2), 229-261. doi:10.1007/s11162-011-9247-y
- George, R. (2000). Measuring change in students' attitudes toward science over time: An application of latent variable growth modeling. *Journal of Science Education and Technology*, 9(3), 213-225. doi:10.1023/A:1009491500456
- Gottfried, A., Fleming, J., & Gottfried, A. (2001). Continuity of academic intrinsic motivation from childhood through late adolescence: A longitudinal study. *Journal of Educational Psychology*, 93(1), 3-13. doi:10.1037//0022-0663.93.1.3
- Greene, B. A. (2015). Measuring cognitive engagement with self-report scales: Reflections from over 20 years of research. *Educational Psychologist*, 50(1), 14-30. doi:10.1080/00461520.2014.989230
- Greene, B. A., & Miller, R. B. (1996). Influences on achievement: Goals, perceived ability, and cognitive engagement. *Contemporary Educational Psychology*, 21(2), 181-192. doi:10.1006/ceps.1996.0015
- Greenfield, T. (1997). Gender- and grade-level differences in science interest and participation. *Science Education*, 81(3), 259-275. doi:10.1002/(SICI)1098-237X(199706)81:3<259::AID-SCE1>3.0.CO;2-C
- Hastie, T., Tibshirani, R., & Friedman, J. (2009). *Elements of statistical learning: Data mining, inference, and prediction* (Second ed.). New York, NY: Springer New York.
- Heddy, B. C., & Sinatra, G. M. (2013). Transforming misconceptions: Using transformative experience to promote positive affect and conceptual change in students learning about biological evolution. *Science Education*, 97, 725-744. <http://dx.doi.org/10.1002/sce.21072>
- Heddy, B. C., Sinatra, G. M., Seli, H., & Mukhopadhyay, A. (2014, April). Transformative experience as a facilitator of interest development and transfer in a college success course for at-risk students. Paper presented at the American Educational Research Association, Philadelphia, PA.
- Hektner, J. M., Schmidt, J. A., & Csikszentmihalyi, M. (2007). *Experience sampling method: Measuring the quality of everyday life*. Thousand Oaks, CA: Sage.
- Itzek-Greulich, H., & Vollmer, C. (2017). Emotional and motivational outcomes of lab work in the secondary intermediate track: The contribution of a science center outreach lab. *Journal of Research in Science Teaching*, 54(1), 3-28. doi:10.1002/tea.21334
- Jakobson, B., & Wickman, P. O. (2008). The roles of aesthetic experience in elementary school science. *Research in science education*, 38(1), 45-65. doi:10.1007/s11165-007-9039-8
- Jang, L. Y., & Liu, W. C. (2012). 2 × 2 achievement goals and achievement emotions: a cluster analysis of students' motivation. *European Journal of Psychology of Education*, 27, 59-76. doi:10.1007/s10212-011-0066-5
- Jin, H., Wei, X., Duan, P., Guo, Y., & Wang, W. (2016). Promoting cognitive and social aspects of inquiry through classroom discourse. *International Journal of Science Education*, 38(2), 319-343. doi:10.1080/09500693.2016.1154998
- Kang, H., Windschitl, M., Stroupe, D., & Thompson, J. (2016). Designing, launching, and implementing high quality learning opportunities for students that advance scientific

- thinking. *Journal of Research in Science Teaching*, 53(9), 1316-1340.
doi:10.1002/tea.21329
- Katz, I., & Assor, A. (2007). When choice motivates and when it does not. *Educational Psychology Review*, 19(4), 429-442. doi:10.1007/s10648-006-9027-y
- Klem, A. M., & Connell, J. P. (2004). Relationships matter: Linking teacher support to student engagement and achievement. *Journal of School Health*, 74(7), 262-273.
doi:10.1111/j.1746-1561.2004.tb08283.x
- Laursen, B., & Hoff, E. (2006). Person-centered and variable-centered approaches to longitudinal data. *Merrill-Palmer Quarterly*, 32, 377-389. doi:10.1353/mpq.2006.0029
- Magnusson, D. (2003). The person approach: Concepts, measurement models, and research strategy. *New Directions for Child and Adolescent Development*, 101, 3-23.
doi:10.1002/cd.79
- National Academy of Engineering and National Research Council. (2014). *STEM integration in k-12 education: status, prospects, and an agenda for research*. Washington, DC: National Academies Press.
- National Academy of Sciences, National Academy of Engineering, & Institute of Medicine. (2005). *Rising above the gathering storm: Energizing and employing America for a brighter future*. Washington, DC: National Academies Press.
- National Research Council and the Institute of Medicine (2004). *Engaging schools: fostering high school students' motivation to learn*. Washington, DC: The National Academies Press.
- National Research Council (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: National Academies Press.
- Newmann, F., Wehlage, G., & Lamborn, S. (1992). The significance and sources of student engagement. In F. Newmann (Ed.), *Student engagement and achievement in American secondary schools* (pp. 11-39). New York: Teachers College Press.
- Nolen, S. B., Horn, I. S., & Ward, C. J. (2015). Situating motivation. *Educational Psychologist*, 50(3), 234-247. doi:10.1080/00461520.2015.1075399
- Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, 25(9), 1049-1079.
doi:10.1080/0950069032000032199
- Patall, E. A. (2013). Constructing motivation through choice, interest, and interestingness. *Journal of Educational Psychology*, 105(2), 522-534. doi:10.1037/a0030307
- Patall, E. A., Cooper, H., & Robinson, J. C. (2008). The effects of choice on intrinsic motivation and related outcomes: A meta-analysis of research findings. *Psychological Bulletin*, 134(2), 270-300. doi:10.1037/0033-2909.134.2.270
- Patall, E. A., Cooper, H., & Wynn, S. R. (2010). The effectiveness and relative importance of choice in the classroom. *Journal of Educational Psychology*, 102(4), 896-915.
doi:10.1037/a0019545
- Pekrun, R. & Linnenbrink-Garcia, L. (2012). Academic emotions and student engagement. In S. L. Christenson, A. L. Reschly & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 259-282). New York, NY: Springer.
- R Core Team (2016). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from <http://www.R-project.org/>

- Reeve, J. (2013). How students create motivationally supportive learning environments for themselves: The concept of agentic engagement. *Journal of Educational Psychology*, 105(3), 579-595. doi:10.1037/a0032690
- Reeve, J., & Tseng, C. (2011). Agency as a fourth aspect of students' engagement during learning activities. *Contemporary Educational Psychology*, 36(4), 257-267. doi:10.1016/j.cedpsych.2011.05.002
- Renninger, K. A., & Bachrach, J. E. (2015). Studying triggers for interest and engagement using observational methods. *Educational Psychologist*, 50(1), 58-69. doi:10.1080/00461520.2014.999920
- Reschly, A. L., & Christenson, S. L. (2012). Jingle, jangle, and conceptual haziness: Evolution and future directions of the engagement construct. In S.L. Christenson, A. L. Reschly, & C. Wylie (2012). *The handbook of research on student engagement* (pp. 3-19). New York: Springer Science. doi:10.1007/978-1-4614-2018-7_1
- Rosenberg, J. M., Schmidt, J. A., & Beymer, P. N. (2017). prcr: Person-centered analysis (R package version 0.1.4.). Retrieved from <https://CRAN.R-project.org/package=prcr>
- Roth, K., & Garnier, H. (2006). What science teaching looks like: An international perspective. *Educational Leadership*, 64(4), 16-23.
- Roth, K. J., Garnier, H. E., Chen, C., Lemmens, M., Schwille, K., & Wickler, N. I. Z. (2011). Videobased lesson analysis: Effective science PD for teacher and student learning. *Journal of Research in Science Teaching*, 48(2), 117-148. doi:10.1002/tea.20408
- Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, 55(1), 68- 78. doi:10.1037/0003-066X.55.1.68
- Salmela-Aro, K., Moeller, J., Schneider, B., Spicer, J., & Lavonen, J. (2016). Integrating the light and dark sides of student engagement using person-oriented and situation-specific approaches. *Learning and Instruction*, 43, 61-70. doi:10.1016/j.learninstruc.2016.01.001
- Shumow, L. & Schmidt, J. A. (2014). *Enhancing adolescents' motivation for science: Research-based strategies for teaching male and female students*. Thousand Oaks, CA: Corwin Press.
- Sinatra, G. M., & Chinn, C. A. (2011). Thinking and reasoning in science: Promoting epistemic conceptual change. In K. Harris, C. B. McCormick, G. M. Sinatra, & J. Sweller (Eds.), *Critical theories and models of learning and development relevant to learning and teaching* (Vol. 1, pp. 257-282). Washington DC: APA Publisher.
- Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The challenges of defining and measuring student engagement in science. *Educational Psychologist*, 50(1), 1-13. doi:10.1080/00461520.2014.1002924
- Schneider, B., Krajcik, J., Lavonen, J., Salmela-Aro, K., Broda, M., Spicer, J., . . . Viljaranta, J. (2016). Investigating optimal learning moments in U.S. and Finnish science classes. *Journal of Research in Science Teaching*, 53(3), 400-421. doi:10.1002/tea.21306
- Sheroff, D. J., Knauth, S., & Makris, E. (2000). The quality of classroom experiences. In M. Csikszentmihalyi & B. Schneider (Eds.), *Becoming adult: How teenagers prepare for the world of work* (pp. 141-164). New York: Basic Books.
- Skinner, E. A., & Belmont, M. J. (1993). Motivation in the classroom: Reciprocal effects of teacher behavior and student engagement across the school year. *Journal of Educational Psychology*, 85(4), 571-581. doi:10.1037/0022-0663.85.4.571

- Skinner, E., Furrer, C., Marchand, G., & Kindermann, T. (2008). Engagement and disaffection in the classroom: Part of a larger motivational dynamic? *Journal of Educational Psychology*, 100(4), 765-781. doi:10.1037/a0012840
- Skinner, E. A., Kindermann, T. A., & Furrer, C. J. (2009). A motivational perspective on engagement and disaffection: Conceptualization and assessment of children's behavioral and emotional participation in academic activities in the classroom. *Educational and Psychological Measurement*, 63 (9) 493-525. doi: 10.1177/0013164408323233
- Skinner, E. A., & Pitzer, J. R. (2012). Developmental dynamics of student engagement, coping, and everyday resilience. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement*, (pp. 21-44). New York, NY: Springer.
- Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education*, 98(3), 487-516.
- van Rooij, E. C. M., Jansen, E. P. W. A., & van de Grift, W. J. C. M. (2017). Secondary school students' engagement profiles and their relationship with academic adjustment and achievement in university. *Learning and Individual Differences*, 54, 9-19. doi: 10.1016/j.lindif.2017.01.004
- Vedder-Weiss, D. (2017). Serendipitous science engagement: A family self-ethnography. *Journal of Research in Science Teaching*, 54(3), 350-378. doi:10.1002/tea.21369
- Von Secker, C. E., & Lissitz, R. W. (1999). Estimating the impact of instructional practices on student achievement in science. *Journal of Research in Science Teaching*, 36(10), 1110-1126. doi:10.1002/(SICI)1098-2736(199912)36:10<1110::AID-TEA4>3.0.CO;2-T
- Wickman, P. O. (2006). *Aesthetic experience in science education: Learning and meaning-making as situated talk and action*. Routledge.
- Wormington, S. V. (2016). *Smooth sailing or choppy waters? Patterns and predictors of motivation in on-line mathematics courses*. Unpublished Doctoral dissertation. Michigan State University.
- Wormington, S. V., & Linnenbrink-Garcia, L. (2016). A new look at multiple goal pursuit: The promise of a person-centered approach. *Educational Psychology Review*, 1-39. Doi: 10.1007/s10648-016-9358-2

Supplementary Material 1

Brief Description of Discrepancies Between Framing Theories and the Present Study

Our definition of engagement and its comprising dimensions is framed by models of engagement articulated by Appleton and colleagues (2006), Fredricks and colleagues (2005), and Skinner and colleagues (2008, 2009). Here we briefly summarize how these models are distinct from one another, and how the definitions offered in these models map on to the conceptual definition of engagement that guides the work of our manuscript. For a more thorough comparison of these models and others the reader is referred to Reschly and Christenson (2012) and Fredricks and McColskey (2012).

Like the framework used in this paper, the engagement model specified by Appleton et al. (2006) includes behavioral, cognitive, and affective dimensions. The behavioral and cognitive dimensions in their model largely align with the definitions we have provided in the paper for these dimensions. However, the affective dimension in this model is defined in terms of a sense of belonging and identification with school, which differs from our description of this dimension in that ours centers on enjoyment and interest. We believe that differences in how we this dimension are largely a result of differences in the grain size of engagement examined. Whereas Appleton and colleagues were interested in capturing engagement at a *larger* grain size (i.e., school identification), this is not a factor that can be meaningfully captured at a *finer* grain size – the momentary level – examined in this study. Affective engagement at a finer grain size might be more akin to a student's interest and enjoyment with respect to a particular subject or learning task. The Appleton model also specifies a fourth engagement dimension called academic engagement, which also refers to engagement at a larger grain size as would be indicated by credit accrual or homework completion rates. Again, this fourth dimension is not relevant to an examination of engagement at a finer grain size and thus was not incorporated into the current study.

Fredricks and colleagues (2005) also posit behavioral, cognitive, and affective dimensions of engagement (though the affective dimension is referred to as *emotional* in their model). Their definitions of the behavioral and affective dimensions are consistent with the constructs used in this paper, but their

cognitive dimension is focused more heavily on students use of particular study and metacognitive strategies rather than on students' perception of importance or value.

The model of engagement proposed by Skinner and colleagues (Skinner et al., 2008, 2009) specifies only behavioral and affective dimensions of engagement (though the affective dimension is referred to as *emotional* in their model), and our definition of each of these constructs align strongly with their model. The Skinner model does not articulate a cognitive dimension, however, but instead includes the construct of *disaffection* in the behavioral and affective (emotional) domains. Disaffection refers to behaviors and emotions that are reflective of maladaptive motivational states. For example, behavioral disaffection would include passivity, inattention and mental disengagement whereas emotional disaffection refers to disinterest, frustration and anxiety. In the current study, we chose to focus on engagement rather than disaffection, so only the engagement components of this model were incorporated into our conceptual framework and analysis.

Supplementary Material 2

Number and Proportion of Learning Activities and Choices

Learning Activities *N* (proportion of responses)

Individual work	671 (.16)
Laboratory	1,023 (.25)
Lecture	556 (.13)
Quiz and test	688 (.17)
Discussion ^a	79 (.02)
Non-instructional ^a	322 (.08)
Presentation ^a	313 (.08)
Video ^a	156 (.04)
Group work ^a	271 (.07)

Choices *N* (proportion of responses)

Time	621 (.12)
Who	473 (.09)
How to do	835 (.16)
Materials	580 (.11)
Other	684 (.13)
Framing	952 (.19)
None	1,869 (.45)

^a Because these learning activities occurred infrequently, they were not included in analysis examining the relationship between momentary engagement profiles and choice.