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Creative Cognition in Secondary Science: An exploration of divergent thinking in science among adolescents

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The divergent thinking skills in science of 282 US high school students were investigated across 16 weeks of instruction in order to determine whether typical academic time periods can significantly influence changes in thinking skills. Students' from 6 high school science classrooms completed the Scientific Structures Creativity Measure (SSCM) before and after a semester of instruction. Even the short time frame of a typical academic term was found to be sufficient to promote both improvements in divergent thinking skills as well as declining divergent thinking. Declining divergent thinking skills were more common in this time frame than were improvements. The nature of student performance on the SSCM and implications are discussed.

Keywords: *Creativity; Higher order thinking; High school*

Creativity is an epistemic aspect of science that is emphasized in reforms as something that should be understood by K-12 students in order to support the development of scientific literacy (Lederman, 1992, 2007; McComas et al., 1998; McComas & Olson, 2002; National Research Council (NRC), 1996, 2000, 2012). Despite the acknowledgement of the critical role that creativity plays in scientific inquiry (SI) and despite the emphasis on SI in K-12 standards documents (Department of Education, 2013; National Curriculum Board, 2010; National Research Council, 2012), there is very little research related to the development of creative thinking skills among science students. Existing studies have examined primary (Liu & Lin, 2014) and secondary (Antink Meyer & Lederman, 2013) teachers' *beliefs* about students'

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scientific creativity and their associated perceptions of related classroom practice. What is needed is an understanding of whether the scientific creativity of students can change across the relatively short time period that corresponds to the time students spend in any given classroom. This basic question has heretofore not been empirically addressed in the secondary grades in the USA (grades 9–12) where students may spend as little as 1, 16-week semester in any science classroom (and less than 5 hours per week). A second purpose of this study was to explore the nature of any changes that occurred. Little work has been done in this area and a major purpose of this study was to generate hypotheses that may be investigated in subsequent research.

Literature and Conceptual Framework

Research on creativity and the development of creativity among students in the age group targeted in this investigation (early to mid-adolescents (approximately ages 14–16)) is first examined. This is followed by a discussion of conceptualizations of creativity among students within science classrooms and a description of how these two research areas were used to inform the present investigation.

Scientific Creativity and Divergent Thinking

Creativity is generally defined as an ability to generate ideas and solutions that are both original (i.e. novel) and appropriate (Amabile, 1996; Kleibeuker, De Dreu, & Crone, 2013; Sternberg & Lubart, 1996). Scientific creativity is conceptualized here to describe the novel thinking that extends and amends our understanding of the natural world. This definition reflects both the general consensus about creativity and science education's recognition of creativity as a characteristic of scientific knowledge (i.e. nature of science (NOS)) due to the processes of its development (i.e. SI) (Lederman, 1992, 2007; McComas et al., 1998; McComas & Olson, 2002). Despite decades of worldwide reform movements that aim to engage students in more authentic science in order to support authentic science skills (Abd-El-Khalick et al., 2004), little research exists on student creativity in K-12 science classrooms. NOS research has established that students and teachers can come to recognize creativity's importance in scientific work (Abd-El-Khalick & Lederman, 2000; Akerson, Abd-El-Khalick, & Lederman, 2000), but whether students' own scientific creativity is shaped within their schooling is presently not understood.

The lack of research on creative thinking in science education is most evident as it relates to the teaching and learning of adolescents. This is despite recognition that the period of mid-adolescence (ages 15–16) represents a peak in divergent, visuo-spatial creativity and in early to mid-adolescence in verbal divergent thinking (Kleibeuker et al., 2013). Divergent thinking is recognized as a critical component of creativity and can be understood as a type of thinking where many, unorganized ideas are elicited by an open-ended task. This is distinct from convergent thinking, an equally important component of creativity, which is typically associated with the analytical evaluation of ideas for the purpose of selecting that, which is best. Divergent thinking was first described by Hargreaves (1927) and was further distinguished from convergent thinking by Guilford (1950) and Hudson (1968). Although no accepted set of factors that contribute to creativity exists, there is a general consensus on divergent thinking as a critical element. Furthermore, there are accepted, validated instruments that assess divergent thinking and this has resulted in a literature base within creativity studies that focus more often on divergent thinking specifically rather than creativity generally.

Four age groups (ages 12–13, 15–16, 18–19 and 25–30) were compared in the Kleibeuker et al. (2013) study in order to describe the trajectory of creativity during adolescence. Participants were asked to complete two divergent thinking tasks: the Alternate Uses Test (Guilford, 1967) and the Creative Ability Test (Van Dam & Van Wesel, 2006). Divergent thinking is typically evaluated by examining participants' performance in three areas on tests such as these: the number of their responses (fluency), the variety of their responses (flexibility), and the novelty of their responses (i.e. originality) on an open-ended task (e.g. uses of a brick). Peak performance on these tasks was found in mid-adolescence when compared to younger students, older adolescents and adults. The authors explained this by comparing the stage of the brain's development in mid-adolescence to that of younger and older participants and asserting that the stage of development for 15–16-year-olds likely supports greater flexibility for learning and creativity.

Given that this period occurs near, what is usually, the end of compulsory schooling in many nations, this peak in divergent thinking ability coincides with students' introductions into more advanced study of scientific phenomena. Understanding whether secondary science classrooms might be influential in shaping students divergent thinking in areas in which they may choose to pursue university study or in which they may be having the last formal science instruction of their lives may provide important insights.

Student Creativity in Science Classrooms

The nature of creativity in general, and divergent thinking specifically, that is relevant to science classrooms is not identical to the conceptualization applicable to creativity among scientists. The developmental level of the students matters and Duckworth (2006) has emphasized that context is critical to a conceptual understanding of creativity that is developmentally appropriate. Scientific creativity in the classroom context must be conceptualized differently from the way it is conceptualized among scientists.

> [W]onderful ideas … need not necessarily look wonderful to the outside world. I see no difference in kind between wonderful ideas that many other people have already had, and wonderful ideas that nobody has yet happened upon. That is, the nature of creative intellectual acts remains the same, whether it is an infant who for the first time makes the connection between seeing things and reaching for them … or an astronomer who develops a new theory of the creation of the universe. (p. 14)

Whether someone else has already had an idea might matter among science practitioners; however, it has no relevance in the classroom environment. This difference in the value of a creative idea has been described by Boden (2004). She distinguishes between a novel idea that is new to *an* individual versus a novel idea that is new to *all* individuals as *psychological* versus *historical* creativity. Clearly, it is psychological creativity that is most relevant to the classroom context. This acknowledgment ceases to undervalue manifestations of divergent thinking that are more likely to be pervasive in science classrooms. Boden argues that creativity is not

> a special 'faculty,' but an aspect of human intelligence in general. In other words, it's grounded in everyday abilities such as conceptual thinking, perception, memory, and reflective self-criticism. So it isn't confined to a tiny elite: every one of us is creative, to a degree. Nor is it an all-or-none affair. Rather than asking 'Is that idea creative, Yes or No?,' we should ask 'Just how creative is it, and in just which way(s)?' Asking that question will help us to appreciate the subtleties of the idea itself, and also to get a sense of just what sorts of psychological process could have brought it to mind in the first place. (Boden, 2004, p. 1)

Boden's perspective is important to the consideration of students' creativity in science classrooms because it broadens the lens through which it has traditionally been explored. Given the Kleibeuker et al. (2013) finding that mid-adolescence is a period of peak creativity on divergent thinking tasks, the purpose of the present study was to understand whether a developmentally appropriate manifestation of scientific creativity might emerge that shows changes that correspond to academic time periods (namely semesters of study) and to explore the nature of any such changes.

Method

Two overlapping research questions guided this study:

(1) Does the scientific creativity of students in mid-adolescence undergo significant changes within the typical academic time period of one semester as measured by divergent thinking tasks?
(2) When changes in students' divergent thinking in science occurs, what is the nature of the changes?

Participants

Six classroom groups took part in this investigation for one semester each. The classroom groups included 282 high school science students from 6 different schools in 3 states in the USA. Students ranged in ages from 14 to 17 and were in grades 9–12. A total of seven teachers were recruited for this study (two of these teachers shared students and were thus treated as a single classroom group) from a variety of communities and classroom environments (urban, suburban, rural, public and private). The selection of a variety of teaching contexts was purposeful. This is an exploratory study that aimed to explore the variety of school contexts typical of the Midwestern USA, where the study took place. The schools in which participants were situated represented a variety of learning communities and the practices of the teachers were inclusive of a variety of strategies and dispositions.

Teachers were recruited by the first author through an email solicitation to science department chairs and instructional coordinators that described the purpose of the study to explore students' scientific creativity in a variety of learning environments for one semester. Each classroom group was administered a pre- and post-semester test of divergent thinking in science (discussed later) Students' performance on the test were shared with teachers after data analysis as a means of member checking (Lincoln & Guba, 1985). Each classroom group is identified by the teachers' pseudonym and is described below.

Dr Larsen. This classroom group was all male and was situated in an urban, private school setting. Students ($n = 65$) from five sections of Dr Larsen's honors and regular chemistry classes took part in data collection. Dr Larsen was a retired professional chemist with a Ph.D. in chemistry who had not received formal pedagogical training or certification but had been teaching for seven years at the time of the study. Students were 15–16 years old and were in 10th and 11th grade.

Mrs Benerito. This classroom group consisted of five sections of regular chemistry classes ($n = 88$) from a public, suburban school. Mrs Benerito held a master's degree in science education and had been teaching for nine years at the time of the study. Students were 15–16 years old and were in grades 10 and 11.

Mr Weder and Mr Hoffman. This classroom group consisted of two sections of an environmental science course ($n = 46$) at a private, semester school. Semester schools recruit students from their home schools to live and study on a campus for one semester to take courses that they will transfer back to their high schools. The semester school had an environmental focus on ecology and all courses were taught with an emphasis on environmental education and stewardship. Both Mr Weder and Mr Hoffman had earned master's degrees in education and both had professional work experience in the fields in which they taught. Mr Weder was also a practicing artist and had been teaching for 10 years at the time of the study. Mr Hoffman had been teaching for 12 years. Their students were 15–16 years old and were in grades 10 and 11.

Mrs Meitner. This classroom group consisted of two sections of an honors chemistry course ($n = 26$) at a public, urban high school. Mrs Meitner had a master's degree in science education and had previous professional experience as a chemist. She had been teaching for 10 years. Students were in grade 10 during their participation and were ages 15–16.

Mr Nobel. This classroom group consisted of an advanced placement (AP) chemistry course ($n = 23$) at a public, suburban high school. AP chemistry is a college-level course taught as a second-year follow-up to honors chemistry. Mr Nobel had a master's degree in chemistry education and was in his 12th year of teaching. This was the second chemistry course the 11th and 12th grade students had taken and they were between 16 and 17 years old.

Mr Venter. This classroom group consisted of five sections of introductory science courses in biology and integrated physics and chemistry ($n = 34$) at a public, rural high school. Mr Venter had been teaching for 11 years and earned a master's degree in education. He had previous work experience in the medical field. Students were in 9th, 10th and 11th, grade and were between 14 and 16 years old.

Both research questions utilized the Scientific Structures Creativity Measure (SSCM) (Hu & Adey, 2002). The SSCM is a measure of divergent thinking that has both verbal (written) and figural (drawing) components. It is based on a three-dimensional model of creativity composed of three attributes (product, trait and process) that reflect three of the four categories of creativity (product, person (trait), process and environment) into which twentieth-century research on creativity was organized. Each category consists of sub attributes that result in 24 distinct attribute/category combinations. These combinations are informed by research, including existing measures, on creativity. The SSCM items were appropriate to the age of the participants and corresponded to the SI skills identified in the NGSS (i.e. science and engineering practices) (NRC, 2012). Table 1 identifies each item on the measure, the associated science or engineering practice, as well as the creative

Table 1. Science practice and creativity process, ability and context for SSCM items

Item	Practice	SSCM Cell
1. Please write down as many possible scientific uses as you can for a piece of glass	Planning and carrying out investigations	Science knowledge (context); fluency, flexibility and originality (ability) and thinking (process)
2. If you could take a spaceship to visit another planet, what scientific questions would you want to explore? Please list as many as you can	Asking questions and defining problems	Problems (context); fluency, flexibility and originality (ability) and thinking and imagination (process)
3. Please think up as many possible improvements as you can to a regular bicycle, making it more interesting, more useful and more beautiful	Constructing explanations and designing solutions	Technical product (context); fluency, flexibility and originality (ability) and thinking and imagination (process)
4. Suppose there was no gravity, describe what the world would be like	Constructing explanations and designing solutions	Phenomena (context); fluency, flexibility and originality (ability); and imagination (process)
6. [a]There are two kinds of napkins. How can you test which is better? Please write down as many possible methods as you can and the instruments, principles and the procedure you would use	Planning and carrying out investigations	Phenomena (context); flexibility and originality (ability) and thinking (process)
7. Please design an apple-picking machine. Draw a picture; point out the name and function of each part	Constructing explanations and designing solutions	Technical product (context); flexibility and originality (ability) and thinking and imagination (process)

[a]Item 5, use as many possible methods as you can to divide a square into four equal pieces (same shape), was omitted. An infinite number of answers are possible and therefore scoring is impossible when a student recognizes that.

thinking process, ability (trait) or context (product) identified by Hu and Adey (2002) in its design.

To the best of our knowledge, the SSCM is the only measure of scientific creativity with acceptable validity and reliability (.875) established by the instrument developers. Previously used in the UK, the participating teachers did not report any concerns or difficulties attributable to cultural issues in item wording. However, the measure was not scored in its entirety due to concern about the appropriateness of one question (item 5, explained in following section). The measure's reliability and validity were thus re-established for the present study with this item omitted. Table 2 describes the reliability data for the unit of analysis, each classroom group. The reliability for the aggregated data is shown in Table 2 as well. Reliability for both the pre- and the post-instruction measure administration were acceptable. The lowest Cronbach Alpha value was .806.

Construct validity was also re-established for the SSCM by the authors because of the omission of item 5. A factor analysis (Table 3) with principal components was run on the sum scores for each item on the pre- and post-test administration and a single factor emerged (Hu & Adey, 2002; Kline, 1993), presumably divergent thinking.

Items six and seven, while sufficient (Kline, 1993), stand out among the other items, however. Ultimately, they were retained because their inclusion did not compromise the integrity of the findings of the study, they are statistically acceptable, they have content validity and each administration of the measure has acceptable reliability.

Data collection. Students with parental consent completed the SSCM outside of class time. There was no benefit to the students for participation although two participating teachers, Mrs Benerito and Dr Larsen, offered students extra credit for submitting the SSCM by a particular date (pre-test in the case of Larsen's students and post-test in

Table 2. SSCM reliability

Teacher	(# classes) Course (# students)	Pre-test Cronbach alpha	Post-test Cronbach alpha
Dr Larsen	(3) Regular Chemistry ($n = 26$)	.854	.840
	(2) Weighted/Honors Chemistry ($n = 36$)	.857	.835
	(5) All Classes ($n = 62$)	.856	.842
Mr Venter	(3) Physical Science ($n = 20$)	.824	.894
	(2) Biology ($n = 14$)	.839	.868
	(5) All classes ($n = 34$)	.828	.900
Mr Weder and Mr Hoffman	(1[a]) Environmental Sciences ($n = 46$)	.847	.857
Mrs Meitner	(3) Weighted/Honors Chemistry ($n = 28$)	.820	.870
Mrs Benerito	(5) Chemistry ($n = 88$)`	.806	.854
Mr Nobel	(2) AP Chemistry ($n = 23$)	.838	.841
Aggregate data	(21) All ($n = 284$)	.850	.860

[a]Weder and Hoffman shared all students and were treated as a single classroom group.

Table 3. Component matrix ($n = 282$)

Item[a]	Pre-test	Post-test
1	.743	.706
2	.798	.779
3	.710	.755
4	.605	.622
6	.526	.452
7	.402	.517

[a]One component extracted.

the case of Mrs Benerito). The amount of time that it took students to complete the test was not a variable of interest and so no effort to control for time was taken though students reported the average as approximately 20 minutes. Also, given that there was no benefit to the students for participating, it was assumed that students would not reproduce one another's work on the pre- and post-test administrations. One instance of replication (i.e. copying) of a single item (item two) was evident from Mrs Meitner's group and both students' data were omitted from data analysis.

Analysis

Dr Larsen was the first participant and completed participation in the spring semester, the remaining participants took part in the fall semester of the following academic year. Therefore, this classroom group's SSCM data were scored first. Consistent labels to all like-responses were assigned in two iterations to ensure consistency. That consistency was checked in a third iteration when the item responses were entered into, and scores were determined by, an Excel database created by the first author. This consistency was maintained by repeating this process as each classroom group's data were entered into the database and scored. This was important because the SSCM collects open-ended responses (Table 1). For example, item 1 asks respondents to identify as many scientific uses as they can for glass and if a student provided *beaker* as a response to item 1 and another student provided *a container used to mix and pour solutions*, it was necessary to ensure that both responses were entered as *beaker* to support validity in the originality data. The Find tool in Excel was used to double-check each new response against existing language in the database for this reason. Although accumulated error must be considered given this analytical methodology, the purpose of this study was to precipitate potential questions and not for the sake of hypothesis testing. Therefore, the accumulated error imposed is acceptable (Lederman & Druger, 1985).

In order to address the first research question, *does the scientific creativity of students in mid-adolescence undergo significant changes within the typical academic time period of one semester as measured by divergent thinking tasks,* the SSCM was scored according to the test developers' protocol (with the exception of item #7 described later) by the first author only and an Excel spreadsheet was developed to compile data and

Table 4. SSCM divergent thinking scores

Divergent thinking score	Definition	Scoring procedure	Items
Fluency	Number of responses	Responses counted	1, 2, 3, 4
Flexibility	Variety of responses ((number of designs (item 6), number of components (item 7)	Organized into categories and number of categories counted	1, 2, 3, 4, 6, 7
Novelty	Originality of responses	2 points if probability of each response is less than 5% and 1 point if between 5% and 10%. 0 point if greater than 10% probability	1, 2, 3, 4, 6, 7

determine scores. The nature of the scores on the SSCM make a single scorer acceptable because the calculation of scores is far less subjective than other open-ended measures. The scores represent a computation of the number of responses (fluency), variety of responses (flexibility) and the statistical probability of the responses (originality). Both the fluency and flexibility scores were calculated by the spreadsheet and the flexibility score was determined in three iterations as previously discussed where an intra-rater reliability of 100% was found. Just as with the Torrance Tests of Creative Thinking that are more common in education, the total score on the measure provides some indication of ability, but it lacks meaning and interpretive power (Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005). Total scores were therefore not determined. Table 4 describes the definitions and procedures by which scores for each item were determined.

Student responses for items 1–4 were simply counted as a measure of fluency (number of responses), organized into categories as a measure of flexibility, and the probability of each response was calculated in order to assign a score for originality (see Table 4). Items six and seven were different in their nature and the number of ideas was an indication of flexibility where fluency was not given a score. The suggested scoring procedure for item #7 was suggested to be valued at the number of functions of the apple-picking machine, significantly minimizing the novelty score, but each function was given three points. This would result in a novelty score that is essentially meaningless statistically. Although the number of functions was maintained as the indicator of flexibility, each was given only one point.

In order to address the second research question, *when changes in students' divergent thinking in science occurs, what is the nature of the changes*, the specific changes that emerged were examined and descriptions of common item responses were compiled using the database developed. The findings and their discussion follow.

Findings and Discussion

With regard to the first research question, *does the scientific creativity of students in mid-adolescence undergo significant changes within the typical academic time period of one* *semester as measured by divergent thinking tasks,* evidence does show that changes in divergent thinking can and do occur across academic terms. With regard to the second research question, *when change in students' divergent thinking in science occurs, what is the nature of the changes,* the changes in divergent thinking were more often negative. A decline in divergent thinking was more likely than an increase during a single semester as measured by the SSCM. Both findings are discussed in the sections that follow.

Result 1: Changes Occur in Student Divergent Thinking in Science Within a 16-week Academic Term

Statistically significant changes in divergent thinking in science emerged in all classroom groups. Only those changes where effect sizes were greater than 0.3 were considered in order to support the validity of the findings. Cohen's (1992) effect sizes were used to inform interpretations of practical significance for those items with statistical significance for each case. Practical significance indicates when results are not likely due to chance and are furthermore, meaningful. Cohen defined 0.2 as an acceptable, small effect size, but given the lack of empirical research on creative thinking in secondary science, the present study considered an effect size of 0.3 as a threshold of practical significance. We did not interpret those statistically significant areas of change in divergent thinking below this value.

As described in the analysis section, there were 6 items on the SSCM instrument that were scored and 16 total scores. This is because four items measure three divergent thinking skills (fluency, flexibility and originality) and two items measure two divergent thinking skills (flexibility and originality). Ten scores that emerged as statistically significant also had effect sizes greater than 0.3. These cumulatively address research question 1 in the affirmative. These 10 scores were statistically significant based on a paired *t*-test ($p < .05$) and had an effect size greater than 0.3; they are disaggregated by classroom group and are reported in Table 5.

Table 5 shows that for the 282 students who completed both administrations of the SSCM, there were changes in divergent thinking skills for all 6 classroom groups. Given that 16 scores were collected for 6 different classroom groups, there are 96 resulting scores and they cannot all be reported here but are reported elsewhere (Antink, 2012). The changes were both positive (i.e. improvements in scores) and negative (i.e. declines in scores) and demonstrate that indeed the divergent thinking component of scientific creativity of students in mid-adolescence can undergo significant changes within the typical academic time period of one semester. Four of the scores were related to the variety of ideas (flexibility) students generated on the tasks in the SSCM, five of the scores were related to the originality (novelty) of their ideas and only one score was related to the number of their ideas (fluency).

It is interesting to note that it was not a matter of quantity (i.e. fluency) in the majority of circumstances. Generating a multiplicity of ideas from which to choose from is a major component of scientific creativity; however, in a 16-week semester, it was not the quantity of students ideas that changed, it was more likely the quality of their ideas. As discussed in the analysis section, the variety/flexibility score was a

Table 5. SSCM areas of improvement and decline

Divergent thinking skill area	Classroom group	*t*	Significance	Pre- to post-change	Effect size (d)
Variety in scientific uses for glass (Flexibility-Item 1)	Dr Larsen	2.726	0.008	Negative	0.338
	Mrs Benerito	−3.075	0.003	Positive	0.327
Originality in Scientific Uses for Glass (Novelty-Item 1)	Dr Larsen	8.148	$p < .001$	Negative	1.01
	Mr Venter	2.806	0.008	Negative	0.481
	Mr Hoffman and Mr Weder	14.93	$p < .001$	Negative	0.492
Variety in Scientific questions about planets (Flexibility-Item 2)	Dr Larsen	2.809	0.007	Negative	0.348
	Mrs Meitner	2.294	0.03	Negative	0.433
	Mr Venter	−2.472	0.019	Positive	0.424
Number of scientific uses for glass (Fluency-Item 1)	Mrs Benerito	−3.634	$p < .001$	Positive	0.387
	Mr Hoffman and Mr Weder	13.253	$p < .001$	Negative	0.437
Originality in scientific questions about planets (Novelty-Item 2)	Mrs Benerito	−6.627	$p < .001$	Positive	0.707
	Mrs Meitner	5.869	$p < .001$	Negative	1.11
Originality in implications of gravity (Novelty-Item 4)	Mrs Benerito	3.432	0.001	Negative	0.366
	Mr Venter	2.772	0.009	Negative	0.661
Originality in product testing design (Novelty-Item 6)	Mrs Benerito	4.468	$p < .001$	Negative	0.487
	Mrs Meitner	3.395	0.002	Negative	0.459
	Mr Nobel	4.107	$p < .001$	Negative	0.856
Variety in implications of gravity (Flexibility-Item 4)	Mrs Benerito	2.555	0.017	Negative	0.483
Originality in bicycle design (Novelty-Item 3)	Mr Hoffman and Mr Weder	−30.603	$p < .001$	Positive	1.01
Variety in machine design (Flexibility-Item 7)	Mr Hoffman and Mr Weder	3.096	0.003	Negative	0.457

measure of the different categories of students' ideas, and suggests that students showed changes in the breadth of their ideas. Five classroom groups showed significant changes in seven scores of flexibility and only two of those seven scores were positive. Similarly, all six classroom groups had significant changes in the originality of student ideas. There were 11 scores (10 scores changed, but some scores had multiple classrooms that changed for the same score) for the total of 6 classroom groups that changed and only two of those 11 scores were positive changes in divergent thinking (see Table 5). Classroom instruction potentially refines students' understanding of science subject matter and perhaps that refinement created cognitive boundaries where students' ideas on SSCM tasks were reflective of some new boundaries. Such an explanation is beyond the scope of the present investigation, but does suggest an area of future research. Ultimately, changes in adolescent creativity are likely even in the brief timespan of one semester. Those changes, however, may not be improvements and the second research question explored the nature of the changes themselves.

Result 2: Declining Divergent Thinking Post-Instruction

Both gains and losses in students' performance on the divergent thinking tasks emerged as described in Table 5. Table 6 identifies the 10 scores in which significant gains and losses by classroom group.

Of the scores in Table 6 where significant changes occurred, the nature of the changes was more likely to be negative. They were more often a decline from pre- to post-administration of the SSCM. When the changes for each teacher's classroom are examined, only three of the six participating groups (Mrs Benerito, Hoffman/Weder, Mr Venter) had scores that showed significant gains after a semester of instruction. All three of those teachers also had scores that declined to a significant degree. The remaining three classroom groups only had scores that changed significantly in the negative direction (Mr Nobel, Dr Larsen, Mrs Meitner).

Further examination of the types of responses given by students on the SSCM illustrates that the most common responses did not necessarily shift even when one of the divergent thinking skill areas did undergo a shift. Table 7 shows the most common idea given for each item (identified in Table 1) on the pre- and post-administration of the SSCM and the percentage of all responses given that were the most common. The gray shaded cells were the most common responses to items where ultimately at least one divergent thinking skill underwent a decline across a semester as shown in Tables 5 and 6. The cells with bolded borders were the most common responses to items where ultimately at least one divergent thinking skill underwent an improvement across a semester as shown in Tables 5 and 6.

Table 6. Classroom group changes in divergent thinking

Divergent thinking skill area	Classroom groups with improvement in divergent thinking skill	Classroom groups with decline in divergent thinking skill
Number of scientific uses for glass (Fluency-Item 1)	Mrs Benerito	Hoffman and Weder
Variety in scientific uses for glass (Flexibility-Item 1)	Mrs Benerito	Dr Larsen
Originality in scientific uses for glass (Novelty-Item 1)	None	Dr Larsen, Mr Venter, Hoffman and Weder
Variety in scientific questions about planets (Flexibility-Item 2)	Mr Venter	Dr Larsen, Mrs Meitner,
Originality in scientific questions about planets (Novelty-Item 2)	Mrs Benerito	Mrs Meitner
Originality in bicycle design (Novelty-Item 3)	Hoffman and Weder	None
Variety in implications of gravity (Flexibility-Item 4)	None	Mrs Benerito
Originality in implications of gravity (Novelty-Item 4)	None	Mrs Benerito, Mr Venter
Originality in product testing design (Novelty-Item 6)	None	Mrs Benerito, Mrs Meitner, Mr Nobel
Variety in machine design (Flexibility-Item 7)	None	Hoffman and Weder

Table 7. Most common responses pre- to post-administration

	Larsen (*n* = 65)		Benerito (*n* = 88)		Weder and Hoffman (*n* = 46)		Meitner (*n* = 26)		Nobel (*n* = 23)		Venter (*n* = 34)	
	Pre (%)	Post (%)	Pre (%)	Post (%)	Pre (%)	Post (%)	Pre (%)	Post (%)	Pre (%)	Post (%)	Pre (%)	Post (%)
1	19.9 Beaker	14.9 Beaker	22.9 Beaker	21.6 Beaker	10.2 Magnify	11 Magnify	13.6 Beaker	11 Microscope	13.8 Evaporation	13 Beaker	19 Beaker	21.2 Beaker
2	15 Water	15.4 Water	19.1 Water	9.6 Water	9.5 Life	9.9 Water	9.1 Water	11.1 Adaptation	9.7 Water	11.4 Adaptation	15.4 Water	11.2 Adaptation
3	8.2 Comfort	9.3 Comfort	9 Paint	8.7 Lights	7.3 Comfort	5 Paint	9.6 Lights	6.3 Motor	7.9 Lights	9.1 Motor	9.3 Comfort	10.9 Comfort
4	21.3 Motion	17.3 Motion	18.4 Motion	16.7 Motion	21.4 Motion	12.1 Motion	18.3 Motion	23.3 Motion	19.1 Motion	13.6 Motion	25.4 Motion	28 Motion
6	35.5 Absorb	42.6 Absorb	48.5 Absorb	47.2 Absorb	27.8 Absorb	29.1 Absorb	39.2 Absorb	40 Absorb	34 Absorb	35.6 Absorb	37.1 Absorb	30.3 Absorb

In 10 out of 13 of these changes, the most common response did not change. The number and originality of their responses may have undergone changes, but the typical response did not. This was the case for both areas of improvement and decline. For two items, complete consistency emerged across all classroom groups. These were item 4, *imagine there was no gravity describe what the world would be like*, and item 6, *describe as many procedures as you can to test two different types of napkins*. The most common response for both of these items for all classroom groups pre- and post-test were related to how human motion would change for item 4 and napkin absorbency for item 6. The purpose in the present study is only to describe the nature of the changes themselves, but these results suggest several areas of inquiry for subsequent investigation.

In the classroom context, it should be emphasized that facilitating creative thinking is potentially time consuming. The findings related to the persistence of the most common responses suggest that the number of student responses and time to consider those responses necessitate the expenditure of time. This is essential to creativity particularly, given that original ideas tend to come later in a set of responses (Mednick, 1962). Time, then, is likely to ultimately emerge as a barrier to the effective inclusion of creativity in science classrooms. It is not a coincidence that time is also considered a primary barrier to SI in the classroom setting as well (Kraus, 2008).

Limitations

There are limitations with this, as with any, study. The content general nature of the SSCM, for example, allows a variety of courses and classrooms to participate in an exploratory study like this one. However, a general instrument likely masks abilities relevant to the subject matter of their specific classroom instruction. The findings related to item #1, scientific uses of glass, suggests this. There were clear patterns given the context and content of students' study. Future study into more nuanced, content-dependent classroom variables necessitates the development of measures that either make explicit specific areas of interest, or are written at a level of generality that allows students to apply knowledge from their own disciplines to the items.

Summary and Discussion

The purpose of the present study was to determine whether one aspect of scientific creativity, divergent thinking, might show changes that correspond to academic time periods (i.e. 16-week semesters) and to explore the nature of the changes that occurred. The period of mid-adolescence has been shown to be a time of higher potential for divergent thinking growth than earlier and later age groups (Kleibeuker et al., 2013), and classrooms do not appear to be an irrelevant factor. The second research question aimed to explore the nature of the changes in students' divergent thinking in science and results provide a pathway for examining the potential for relationships between classroom environments, instruction and divergent thinking in subsequent investigations.

First, although improvements in divergent thinking may be desirable, the US- based science classrooms in the present study were more likely to promote declines in divergent thinking ability. There is a theory of scientific creativity (Simonton, 2004) that may provide an explanation for why this may be more likely as subject matter knowledge increases. In Simonton's model of scientific creativity, he explains the differences in peak creative performance (in terms of age and education) of different scientific fields as a reflection of the body of existing conceptual and process knowledge in that field. Biologists' creative productivity is found to peak much later than scientists in theoretical physics Simonton reasons, because the extent of the existing knowledge in the biological sciences is greater. Simonton claims that the decline in creative production that is seen in patent, grant and publication data for the sciences is a reflection of something akin to indoctrination. Scientists' ideas become bounded by the knowledge and investigative practices of their disciplines and the chances of experiencing the kind of insights that support paradigmatic change become smaller. Perhaps there is a similar phenomenon that occurs in the process of schooling. The knowledge gained across 16 weeks of instruction in students' first biology course or chemistry course may have served to narrow ideas. Determining whether this is actually the case, however, requires a measure of divergent thinking that is not general in nature as the SSCM is.

Creativity is critical to the practice of science. It is through creativity that new ideas are born, new methodologies developed and new technologies are realized. Supporting science students in the development of both their understandings about creativity in science and their creative abilities, including divergent thinking, related to scientific practice seems intuitively essential. However, the nature of the relationships between classroom environments and the development of divergent thinking in science is ultimately more complex than may have been previously assumed.

Disclosure statement

No potential conflict of interest was reported by the authors.

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