Transient and Robust Knowledge: Contextual Support and the Dynamics of Children's Reasoning About Density

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ABSTRACT—Contextual support for performance and understanding plays an important role in learning and teaching. This study investigated the temporal course of the effects of support—how it affects complexity and correctness of judgments about density in kindergarten (n = 35) and second-grade (n = 29) children. In the experimental group, a teacher provided support through modeling more complex reasoning about why objects sink or float. Children's complexity judgments increased sharply with support compared to no support, although their predictions about whether objects would sink or float were mostly correct from the start. Following the support event, children showed a sudden jump in complexity of explanations, which was transient for most children, who showed either rapid decrease or some oscillation and then decrease. A few sustained the high-level explanation after the jump, showing robust knowledge. That is, patterns of performance across trials were primarily nonlinear, following mostly cubic or quadratic change. In addition, second-graders had a more complex understanding of density than did kindergarteners. Findings indicate that children's concepts are dynamic rather than static, as evidenced by the strong but transient effects of support for most students. To move from transient to robust knowledge requires the building of knowledge and skill over time.

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Science educators agree that children need to evaluate evidence to acquire scientific knowledge at a young age (National Committee on Science Education Standards and Assessment, National Research Council, 1995). Unfortunately, such skills are difficult to acquire, especially for young children (Ross, 1988). To aid students in acquiring new scientific knowledge, teachers often offer support and guidance as children evaluate evidence and encounter new phenomena. Though such support is often used to facilitate learning, little is known about how children's knowledge shifts and changes over time following supportive interactions. Knowledge of the temporal course of the effects of support will elucidate the effectiveness of methods for providing support and guiding students to robust knowledge without support. The present study investigated how young children's theory of one aspect of everyday physics—the understanding of density—varied following the provision of contextual support by a skilled adult.

Contextual Support During Teaching, Learning, and Development

One of the core hypotheses of some strands of developmental theory is that cognitive performance varies with contextual support (Fischer, 1980; Fischer & Bidell, 1998; Vygotsky, 1978). According to this hypothesis, cognitive competence is not fixed but varies as a function of the presence or absence of support. For example, a student pitching a baseball will be more likely to perform at an optimal level with a catcher who is very skilled at offering support and guidance than when the pitcher is paired with a catcher who offers no support. The less-skilled pitching performance with the unsupportive catcher is not an illusory departure from the pitcher's real and fixed competence with pitching but instead a real change based on the effects of the catcher's activities such as the prompts levied by the catcher and the ways that his actions mesh with the needs of the pitcher.

Such variation in cognitive performance is hypothesized to vary within a range such that competence is low or at a functional level without support and high or at an optimal level with support (Brown & Reeve, 1987; Fischer, Bullock, Rotenberg, & Raya, 1993; Watson & Fischer, 1980). A number of studies have demonstrated that support can powerfully affect children's cognitive performance. For example, Pacifici and Bearison (1991) compared the performance of 29 3-year-olds working on puzzles before and after several different kinds of adult assistance with a similar puzzle. The research revealed that all of the children performed better after the support event, with the group of children who received the carefully calibrated support of the researcher performing the best. Similarly, Day and Cordon (1993) examined the effect of support calibrated to third-graders' ongoing performance during a balance-scale task (adapted from Siegler, 1976) controlling for the effect of various child characteristics including impulsivity and verbal intelligence. Children in the supported condition did better on the task.

Most research has neglected an important aspect of the effect of support—its temporal course—which seems to show an abrupt, transient increase followed in a short time by a decrease to prior levels (Fischer & Bidell, 2006; Fischer et al., 1993). That is, as a result of support children's performance spurts to a higher, optimal level, which is sustained for only a brief time; performance then falls to a lower, functional level. The present study is the first that we know to investigate systematically the temporal pattern of the effects of support.

Prior studies established a common set of characteristics for providing support during teaching and learning (Stone, 1998; van Geert, 1998). First, the child must be participating in a task currently beyond his or her understanding or current competency without support. Second, the adult should make constant assessments of the child's understanding during the task. Third, under ideal instructional conditions, an adult will vary the type of support provided to the child depending on the needs of the child. Finally, a distinction is made between simple contextual support and scaffolding (Fischer & Bidell, 1998). Under scaffolding, the adult and child coparticipate in the task, with the adult performing part of the task to help the child complete it; under simple contextual support, the more skilled partner models, prompts, and otherwise encourages the novice partner but does not directly participate in the task. This contextual support without scaffolding promotes the child's performance to reach the optimal level in his or her developmental range of cognitive competence. Though contextual support and its immediate effect have been described in the research literature, to our knowledge, there are currently no studies that describe how these effects persist or dissipate over time directly following the support event.

The current study focuses on examining the temporal effect of contextual support on young children's reasoning about density as it varies after the support event.

Previous Research on Children's Reasoning About Buoyancy

With children's reasoning about density as the focus of this study, a survey of research describing the developmental progression of such competence is necessary to identify the hierarchical order of thinking expected during the experiment. Beginning with Piaget (1930), researchers have examined children's understanding of density. Because buoyancy is a visible consequence of density (Kohn, 1993), developmental research has focused on participants' predictions and explanations about objects' buoyancies.

Early on, Piaget (1930/1960) argued that children go through four main stages in their understanding of why things sink or float. In the first stage, which children reach between 4 and 5 years of age, their explanations do not correspond with their observations. Instead, children appeal to moral reasons as to why things float (e.g., "the stone is clever"). During Stage 2, 5- to 6-year-old children rely on dynamism, explaining the material world in terms of active forces, to argue that heavy objects sink—for example, using the word heavy to mean strong rather than felt weight. Once children reach Stage 3 (at about 6–8 years of age), they appeal to an object's lightness to account for why it floats. Finally, when children enter Stage 4 at approximately 9 years of age, they begin to consider both volume and weight in relation to liquid in their explanations. It is not until this late stage that children differentiate weight from density. The developmental progression in understanding has been replicated by other researchers (e.g., Laurendeau & Pinard, 1960; Smith, Carey, & Weiser, 1985).

More recent research suggests that children have some tacit knowledge of buoyancy by age 4 (Esterly, 2000; Kohn, 1993). Esterly found that at 4½ children provided explanations based on weight and material kind, which predominate into adulthood. Children's explanations based on material kind, weight, and density correlated with their correct judgments. Thus, explanations may be necessary to tap into children's implicit theories of density. In sum, young children demonstrate some understanding of density. However, the evidence suggests that there is much they can continue to learn. Following from Piaget's (1930/1960) and the other work described here, the present study focused on the examination of children's understanding of buoyancy as illuminated by their explanations.

The Current Study

Our study differed from previous research in that we examined how children's reasoning about buoyancy shifted and then changed over time following the receipt of contextual support. To our knowledge, no other studies have simultaneously examined the immediate effects and then the temporal course of the persistence and/or dissipation of the effects after support is removed. We examined one type of contextual support called modeling, where the more skilled adult provides the student with a model response to the question of why an object sinks or floats. Assessment of the same concept with a series of distinct objects made it possible to see the temporal course of the effects of support across trials. We also assessed whether the process of experimenting with objects in water had an effect on children's concepts of buoyancy, either independent of or in addition to the effects of modeling. Finally, the impact of contextual support on the correctness of children's predictions about whether objects would sink or float was assessed as an additional dimension of children's thinking about buoyancy.

We focused on kindergartners and second-graders in this study. Based on prior research, we expected that these two age groups would have different concepts of buoyancy, with the second-graders' representations being more complex and accurate. By choosing to study kindergartners, we were able to examine concepts in very young children who were still developing the concepts, while at the same time having some experience with formal schooling. We expected both groups' concepts to fall short of a complete concept of buoyancy.

The following hypotheses were tested:

1. Seven-year-old children will give more complex answers than will 5-year-old children.
2. Children will give more complex answers after they receive support compared to children who do not receive support.
3. The effect of support will dissipate relatively quickly over time following the support event.
4. Support for complex explanations may also increase correct predictions in the experimental condition; practice effects should be present in both conditions.

METHOD

Participants

The sample consisted of 39 kindergarteners (17 girls and 22 boys) and 25 second-graders (14 girls and 11 boys) from two large cities in the northeast United States. Twenty-four of the kindergarteners and 13 of the second-graders were in the experimental (high support) condition. Fifteen of the kindergarteners and 12 of the second-graders were in the control condition. Random sampling created uneven cell sizes. Sixteen children (25%) were African American or Black, 32 (50%) were European American, 4 (6.3%) were Latino/a, 7 (11%) were Middle Eastern, and 5 were Asian (8%). Children were sampled from middle and working-class communities.

Procedure

Children were recruited from schools and after-school programs in the two cities. Children were interviewed individually outside their classrooms. Interviews were audiotaped.

Pretest Session

The researcher asked children to predict whether each of eight common objects would sink or float. Following each prediction, children were asked to justify the reasoning behind their buoyancy prediction. Next, children tested their prediction individually by placing the object into a bucket of water and explaining why the object sank or floated. Children selected the objects one at a time until they had done all of them. The objects included a rubber ball, four different blocks, an empty bottle, an eraser, and a metal magnet. Children then participated in either the high-support or control conditions, in which, after support, they repeated the task with the eight objects.

Experimental Condition: High Support

Following the initial session, the experimenter provided support by modeling a justification for whether something would sink or float using four objects one at a time—an empty bottle, a block, a metal key ring, and a rubber ball. For example, the experimenter told the children, "Here's a bottle. I think it will float because it is light for its size in the water." She then tested the object and said, "Yes, I'm right. The bottle floated because it is light for its size in the water." For each object, the experimenter said twice that it would either float or sink because it was light or heavy "for its size in the water."

Control Condition: Low Support

For the low-support condition, the experimenter predicted whether the four objects (i.e., an empty bottle, a block, a metal key ring, and a rubber ball) would sink or float. The experimenter did not give a reason for her predictions. Thus, the support in the experimental condition specifically targeted the explanation, while the control condition focused on only the prediction.

Posttest Session

After the experimenter either made predictions for the four objects (control, low-support condition) or predicted and justified the predictions (high-support condition), the initial procedure was replicated exactly with children asked to predict whether the same original eight objects would sink or float and to justify their predictions. The session ended with children explaining whether an object had sunk or floated and why.

Coding Buoyancy

Children's answers to whether objects would sink or float were coded as correct, incorrect, or no answer. In addition, we constructed a Guttman-type scale based on skill complexity (Fischer, 1980; Fischer & Bidell, 1998) to assess the developmental levels of children's answers to why they thought that something would sink or float. Under Fischer's framework, symbolic thought typically emerges under optimal conditions across many domains between 18 and 24 months of age in the form of single representations. It is preceded as early as 10–14 months by sensorimotor action systems and then develops over the next several years through levels of increasing complexity that relate representations to each other.

Table 1 displays the coding scheme and provides examples of children's responses. Answers ranged from the level of sensorimotor system to that of representational system. At the level of sensorimotor system, children relate the name for an object to their perceptions and actions on the object—for example, stating the name of the object. With a *single representation,* children identify specific characteristics of the thing represented; the object is light and it floats. An object is heavy and it sinks. Representational mappings emerge next under optimal conditions between 3.5 and 4.5 years of age. With a *representational mapping*, a child can coordinate two or more representations or variable attributes of the object into a single relational skill. An object floats because it is light and small. Another object floats because it is heavy and large. Two previously unconnected single representations about the object (e.g., the object is heavy; the object is large) are coordinated to form the concept of floating or being buoyant. Finally, *representational systems* emerge under optimal conditions between 6 and 7 years of age. With a representational system, a child can coordinate two or more representational mappings into a system of representations linking multiple variables, such as the concept of buoyancy. An object floats because it is light for its size in the water, and an object sinks because it is heavy for its size in the water.

Based on their complexity, children's answers were given scores ranging from 1 (i.e., *sensorimotor system*) to 5 (i.e., *system*). When children did not answer or said that they did not know, they were given a score of zero for complexity.

Reliability

To test for intercoder reliability, each coder independently coded 20 children's responses (31% of the data set). Coders did not explicitly know to which condition children were assigned. Reliability was evaluated using kappa coefficients. According to Fleiss (1981), kappa coefficients above .75 reflect excellent agreement. An overall kappa of .82 was obtained for the level of reasoning a child evidenced for why an object sank or floated and .89 for whether children correctly predicted whether an object would sink or float. Disagreements were resolved through discussion.

RESULTS

Nearly all children performed at a higher complexity level immediately after support, and the effect dissipated for most children over the eight trials, with many children showing a rise again on one or two later trials. A few children sustained their high-level explanations. Support did not affect the children's predictions about floating and sinking, although performance did improve in both conditions during the session.

Analysis Plan

We first report descriptive statistics. Next, we report significant main effects and significant interaction effects pertinent to the hypotheses. Analysis of variance (ANOVA) and *t*-test procedures were used to test our hypotheses. We provide η^2

Table 1
Coding for Representation Level of Buoyancy Understanding Using Skill Theory

Complexity level	*Code*	*Description*	*Example*
Sensorimotor systems	1	The child encodes the identity of the object and not an attribute of the object	The ball will float because it is a ball
Single representation	2	The child notes one attribute of the object	The ball will float because it is light
Representational mapping	3	The child coordinates two attributes of the object	The ball will float because it is tiny and light
Representational transitional mapping	4	Coordinates two mappings: (a) rudimentary concept of density coordinated with concept of buoyancy or (b) representation(s) of the water and the object coordinated by concept of buoyancy	(a) the ball will float because it is light for its size or (b) the ball will float because it is light in the water
Representational system	5	Coordinates two or more representational mappings under a single concept; rudimentary concept of object density coordinated with representation(s) of the water under single concept, buoyancy	The ball will float because it is light for its size in the water

estimates to indicate a measure of the proportion of variance accounted for by a predictor. η^2s between .01 and .09 indicate a small effect size, η^2s between .09 and .24 indicate a medium effect, and η^2s greater than .25 indicate a large effect (Cohen, 1988).

These analyses were followed by individual growth modeling (Singer & Willett, 2003). We used this approach to further investigate the impact of support on children's cognitive performance, analyzing each child's specific rate of change over the test period. The SAS PROC MIXED procedure was used to fit all models in this analysis. (For a detailed discussion of the use of SAS PROC MIXED in fitting individual growth models, see Singer, 1998.)

Preliminary Analyses and Data Screening

Prior to conducting statistical tests, we examined the data for differences based on place of residence, gender, and ethnic background. Children's percentage of correct answers about whether objects would sink or float during the pretest and the posttest were computed separately by taking the total number correct and dividing it by the eight trials for each condition. The possible range of scores extended from 0% to 100% on the pretest and posttest. Similarly, to screen the data for the level of children's justifications of why objects would sink or float, an arithmetic mean was calculated for children's mean complexity level across the eight different objects. This mean, computed separately for pretest and posttest, could vary from 0 to 5. There were no significant differences for gender, ethnicity, or city of residence in children's (a) mean correct responses to whether objects would sink or float in the pretest, (b) mean correct responses to whether objects would sink or float in the posttest, (c) mean skill level in the pretest, or (d) mean skill level in the posttest. Thus, these factors are not included in future analyses.

Hypothesis 1: Age and Condition Effects for Complexity of Judgments

Hypothesis 1 was supported: Older children were more advanced in their skill level than younger children, and children assigned to the high-support condition made more complex judgments in the posttest than children in the control condition (Figure 1). To test these hypotheses, a Condition (high support, control) × Age (kindergarteners, second-graders) × Test Time (pretest, posttest) × Trial (Trials 1–16) mixed-design ANOVA was conducted. Condition and grade served as between-participant factors, and test time and trial served as within-participant factors. There was no difference in the mean complexity ratings on the pretest of children assigned to the control ($M = 2.06$, $SD = 0.57$) versus high-support conditions ($M = 2.04$, $SD = 0.38$), $F(1, 62) < 1$.

As predicted, a main effect for grade indicated that second-graders ($M = 2.53$, $SD = 0.34$) answered questions at a higher level than did kindergarteners ($M = 2.04$, $SD = 0.65$), $F(1, 60) = 14.90$, $p = .0001$, $\eta^2 = .20$. During the pretest, kindergarten children scored at a mean level of 1.88 ($SD = 0.50$), while during the posttest, they scored at a mean level of 2.19 ($SD = 0.91$). Second-graders scored at a mean level of 2.30 ($SD = 0.24$) and at a mean level of 2.75 ($SD = 0.66$) for pre- and posttests, respectively.

Additionally, the ANOVA revealed a main effect for condition, with children assigned to the experimental condition scoring higher ($M = 2.35$, $SD = 0.58$) than children assigned to the control condition ($M = 2.06$, $SD = 0.60$), $F(1, 60) = 5.07$, $p = .03$, $\eta^2 = .08$. Children also scored lower on the pretest ($M = 2.05$, $SD = 0.47$) than on the posttest ($M = 2.41$, $SD = 0.86$), $F(1, 60) = 16.60$, $p = .0001$, $\eta^2 = .22$. Confirming the second part of Hypothesis 2, a significant Condition × Time interaction effect qualified the previous two findings, $F(1, 60) = 15.30$, $p = .0001$, $\eta^2 = .20$. Using a Bonferroni correction, the alpha level was set at .01 for follow-up t tests. Follow-up t tests indicated that children assigned to the experimental condition significantly increased their mean complexity level on the posttest ($M = 2.66$, $SD = 0.92$) after participation in the intervention compared to their pretest scores ($M = 2.04$, $SD = 0.38$), $t(72) = 3.79$, $p = .0003$. This difference represents more than a half step in mean complexity. In contrast, children assigned to the control condition had the same mean complexity level on the posttest ($M = 2.07$, $SD = 0.65$) compared to the pretest ($M = 2.06$, $SD = 0.57$), $t(62) = .19$, $p = .85$.

The ANOVA revealed three significant interaction effects, which generally supported the hypotheses. First, there was a significant Time × Trial × Condition interaction effect, $F(7, 54) = 2.54$, $p = .03$, $\eta^2 = .25$. Paired sample t tests indicated that children in the experimental condition improved their performance between the pretest and posttest for all trials. In contrast, children in the control condition did not increase their mean skill level in any trials from the pretest to the posttest. Using a Bonferroni correction with an alpha of .003 to all follow-up t tests, children in the experimental condition increased in their mean complexity level for Trials 9, 10, 12, and 16 in the posttest compared to the pretest. Additionally, holding time and condition constant, there was a significant quadratic trend for children in the experimental condition on their posttest trial scores, $F(1, 35) = 6.15$, $p = .02$, $\eta^2 = .15$. Figure 1 displays the mean complexity level for all the trials across the two age groups. Second, after application of a Bonferroni correction with an alpha of .003, second-graders improved their performance on Trial 3.

Finally, there was a significant Time × Trial × Condition × Age interaction effect, $F(7, 54) = 2.90$, $p = .01$, $\eta^2 = .27$. This interaction was explored by holding age and condition constant. None of the paired trials were significantly different from each other for the kindergarteners in the control

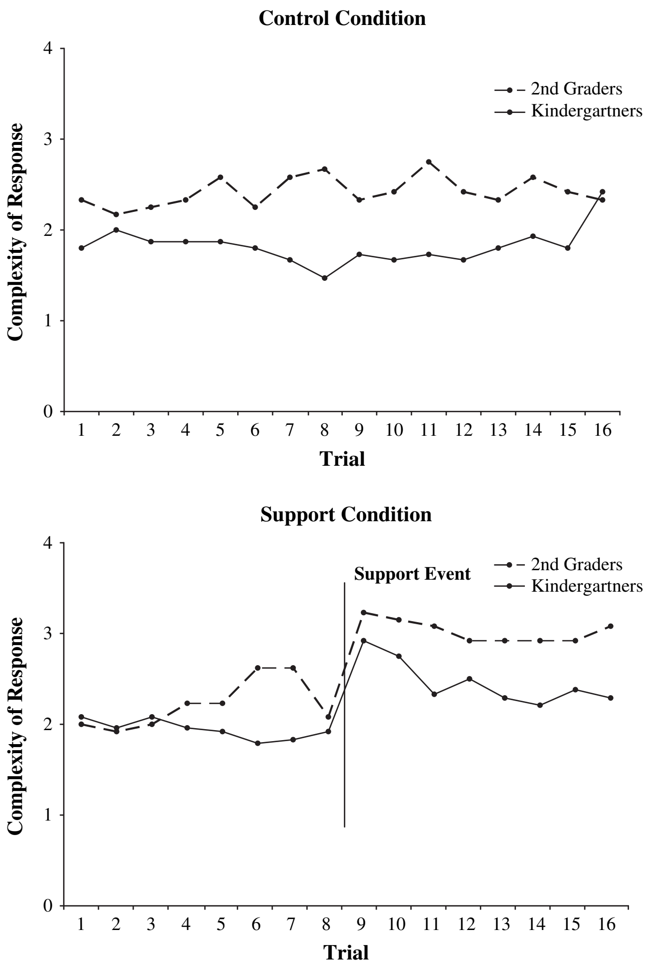

Fig. 1. Mean complexity levels across trials, kindergarten, and second-grade children.

conditions. Application of the Bonferroni method resulted in an alpha of .002 (.05 divided by 32 tests). With this correction when assigned to the experimental condition, kindergartners showed a mean increase in their complexity level for Trial 10, while second-graders showed an increase for Trials 9 and 10. Whereas there was a significant quadratic trend for kindergarteners in the second 8 trials, $F(1, 23) = 7.52$, $p = .01$, $\eta^2 = .25$, the quadratic trend was not significant for second-graders, $F(1, 12) = 1.19$, $p = .30$.

Hypotheses 2 and 3: Change in Complexity Following Support

These findings indicate that support had the predicted effect on complexity, which increased sharply and then dissipated quickly over time for most children (Figure 1). To test Hypotheses 2 and 3 more precisely, we constructed a growth model to describe the change pattern of the complexity of children's responses as they differed by age and condition over the period of assessment (see Singer & Willett, 2003, for a description of individual growth modeling). The SAS PROC MIXED procedure was used to fit all models in this analysis. The dependent variable was the complexity (skill level) of children's explanations of why objects sank or floated at each of 16 trials in time series.

The findings for age and condition were replicated in the growth analysis (Table 2, Model A). Children in the experimental condition improved their performance between the pretest and posttest by half a skill level on average ($\beta = .55$, $p < .001$). Second-graders answered questions at a higher level than did kindergarteners across all trials ($\beta = .37$, $p < .01$). There was no interaction effect between age and condition.

Visual inspection of the participants' growth trajectories indicates that their performance spurted nonlinearly following the support event. Eighty-five percent of children in the support condition improved their performance following support. Among the children who exhibited an improvement in their performance, most exhibited a polynomial change trajectory over the course of the trials following support. Prototypical plots of representative children for each pattern of change are illustrated in Figure 3. For Pattern A, 58% of the children in the support condition exhibited a cubic change trajectory after receiving support (Figure 3, Pattern A): After the sharp increase, their performance dropped, increased again once or twice, and ended at a lower level. With Pattern B, 20% exhibited an initial increase and then decreased their performance in either a quadratic or linear pattern (Figure 3, Pattern B). In Pattern C, the remaining 22% of children in the support condition sustained their high level of performance across the remaining trials, exhibiting no drop after their performance increased (Figure 3, Pattern C).

Rather than fitting a unique polynomial for each child, we selected a cubic model because it was the predominant pattern, it incorporates lower order polynomials in the analysis, and no child's performance needed a higher order polynomial. Table 2 presents the results of fitting four models of increasing polynomial complexity to the skill level data. The table includes both the fixed and random effects from each model. Goodness of fit was determined using the Akaike Information Criterion statistic (where smaller is better) and by determining the difference in the deviance statistic between each sequential model and comparing it to the appropriate critical value of a chi-square distribution.

The cubic model was the best fit to the data. Comparing the quadratic (C) to the cubic model (D), we found the deviance statistic declined by 21.1, which exceeds the critical value of a chi-square distribution on five degrees of freedom (11.07). Thus, we reject the null hypothesis that all five parameters are simultaneously zero and conclude that there is potentially predictable variation in curvature across children. Notice that the variance components in the final cubic model (D) are significant, whereas the associated fixed effects are not. This finding was more or less expected because each of the parameters for

Table 2
Comparison of Fitted Alternative Polynomial Change Trajectories of Children's Skill Level Data After the Modeling Event ($n = 64$)

	Model A, no change	*Model B, linear change*	*Model C, quadratic change*	*Model D, cubic change*
Fixed effects composite model				
Intercept (skill level before trials)	1.83 (0.67)***	1.85 (0.06)***	1.85 (0.06)***	1.84 (0.06)***
SUPPORT (effect of support)	0.55 (0.05)***	0.61 (0.11)***	0.72 (0.13)***	0.46 (0.24)*
AGE (effect of age)	0.37 (0.13)**	0.28 (0.11)*	0.29 (0.09)**	0.32 (0.11)**
TIME (linear term)		−0.20 (0.02)	−0.10 (0.09)	0.20 (0.27)
$TIME^2$ (quadratic term)			0.01 (0.01)	−0.08 (0.08)
$TIME^3$ (cubic term)				0.01 (0.01)
Variance components				
Level 1: within person	0.35 (0.02)***	0.30 (0.01)***	0.27 (0.01)***	0.26 (0.01)***
Level 2: before trials status	0.21 (0.04)***	0.14 (0.03)***	0.13 (0.03)***	0.13 (0.03)***
Linear term				
Variance		0.02 (0.004)***	0.13 (0.04)***	0.54 (0.17)***
Covariance with support status		0.03 (0.01)**	−0.05 (0.03)-	0.08 (0.06)
Quadratic term				
Variance			0.002 (0.001)**	0.04 (0.02)**
Covariance with support status			−0.01 (0.004)	−0.02 (0.02)
Covariance with linear term			−0.02 (0.004)**	−0.15 (0.06)**
Cubic term				
Variance				0.001 (0.00)*
Covariance with support status				0.002 (0.002)
Covariance with linear term				0.01 (0.004)**
Covariance with quadratic term				−0.004 (0.002)*
Goodness of fit				
Deviance statistic	1795.9	1671.1	1624.5	1603.4
AIC	1805.9	1687.1	1648.5	1637.4
BIC	1817.1	1705.0	1675.4	1675.4

Note. Model A is the no change trajectory, Model B is the linear change trajectory, Model C is the quadratic change trajectory, and Model D is the cubic change trajectory. Standard errors are in parentheses. AIC=Akaike Information Criterion; BIC=Bayesian Information Criterion.
*$p < .05$.**$p < .01$.***$p < .001$.

time is collinear. The nonzero variance component suggests that there is predictable variation in the curvature of children's performance trajectories. Specifically, while, on average, the various curvatures of children's performance graphs may pool to zero, they differ by certain individual difference characteristics. Presumably, these would not involve simple relations with age or gender because there were no significant interactions between time and age or gender found here.

In summary, most children showed an abrupt spurt in performance after support followed by a decrease. Many showed a general decrease but returned to a higher level on one or two specific trials (fitting a cubic pattern). Some simply decreased (linear or quadratic patterns). Some sustained the high level across all trials. These are the kinds of differences expected in a dynamic change process.

Hypothesis 4: Correct Judgments

Hypothesis 4 asked whether support for complex explanations in the high-support condition would produce more correct predictions about whether an object would sink or float in the posttest than in the pretest, as well as whether support for correct predictions in both conditions led to an increase in correct predictions. To test this hypothesis, a Condition (control, high support) × Grade (kindergarteners, second graders) × Test Time (pretest, posttest) × Trial (Trials 1–16) mixed-design ANOVA was carried out.

Condition and grade served as between-participants factors, while test time and trial served as within-participant factors. There was no significant main effect of condition, $F(1, 60) < 1$, age, $F(1, 60) = 1.10$, *ns*, nor a Condition × Age interaction effect, $F(1, 60) < 1$. No interactions with condition were significant (Figure 2).

Not surprisingly, however, children were more likely to make correct predictions about sinking and floating during the posttest (M = 89% correct, SD = 14%) than during the pretest (M = 71% correct, SD = 16%), $F(1, 60) = 77.15$, $p = .001$, $\eta^2 = .56$ (Figure 2). The effect of trial was significant, $F(7, 54) = 3.28$, $p = .006$, $\eta^2 = .30$. There was no spurt in performance after support but a gradual increase from high performance to even higher in both conditions. A spurt would be unlikely (impossible for second-graders) because performance was already high at the end of the pretest period. See Figure 2 for percentages of children's correct judgments. Pairwise comparisons indicated that children were more likely to answer correctly during Trials 6 (M = 86% correct, SD = 24%) and 8 (M = 91% correct, SD = 22%) than during Trials 1 (M = 77% correct, SD = 31%), 3 (M = 71% correct, SD = 33%), or 4 (M = 73% correct, SD = 30%). Children were also more likely to answer correctly during Trial 8 than during Trials 2 (M = 84% correct, SD = 25%), 5 (M = 80% correct, SD = 29%), or 7 (M = 80% correct, SD = 32%). In general, children scored better the longer that they participated in the study. The quadratic, $F(1, 60) = 5.84$, $p = .02$, $\eta^2 = .08$, and order 5 equations, $F(1, 60) = 8.90$, $p = .004$, $\eta^2 = .13$ were also significant.

Finally, there was a significant Time × Trial interaction effect, $F(7, 54) = 2.30$, $p = .04$, $\eta^2 = .23$. During the first eight trials, children were more accurate during Trial 8 (M = 88% correct, SD = 33%) than during Trials 1 (M = 63% correct, SD = 49%), 2 (M = 73% correct, SD = 45%), 3 (M = 63% correct, SD = 49%), and 4 (M = 61% correct, SD = 49%). During the second eight trials, no pairwise comparisons were significantly different from each other.

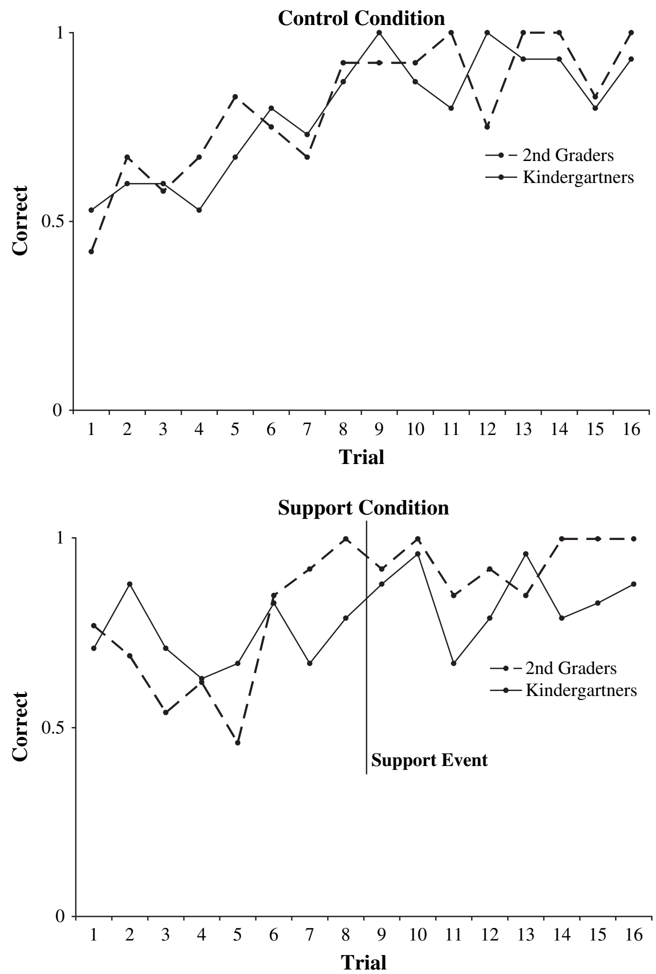

Fig. 2. Mean correct responses across trials, kindergarten, and second-grade children.

DISCUSSION

Contextual support for explanation creates a sharp increase in skill complexity, but most children cannot sustain this high level. Their performance decreases back to their ordinary, functional level of skill—sometimes quickly, sometimes over a period of time. Instruction situations typically involve frequent provision of support, and consideration of the typical transience of support effects needs to be integrated centrally into construction. Many teachers make this adjustment intuitively, but research on the temporal course of support effects can help shape more effective instruction.

The results strongly supported three of the hypotheses. First, the second-graders gave more complex explanations about why objects sank or floated than the kindergartners across trials and conditions. Second, and central to the focus of this study, children in the high-support condition gave more complex explanations directly following support and on some several trials thereafter. Among children exhibiting an improvement in their performance following support, most exhibited a polynomial change trajectory over the course of the trials following the support event, with 58% of the children exhibiting a cubic change trajectory and 12% exhibiting a quadratic change trajectory. With regard to the fourth hypothesis, children's predictions of sinking or floating were generally high in both grades, although there was an increase from the pretest to the posttest. Their answers did not vary across the support and control conditions.

Effects of Contextual Support and Children's Learning

The central goal of the present study was to examine children's understanding of buoyancy as it varied under conditions of contextual support and to describe the time course of the effects of support. We found several results that are simultaneously consistent with and illuminate current developmental theory regarding the effects (immediate and over time) of contextual support on cognitive performance within children's thinking about density.

First, the children did not demonstrate one consistent level of competence concerning buoyancy concepts but instead they showed a range or zone of levels (Brown & Reeve, 1987; Vygotsky, 1978; Watson & Fischer, 1980). This developmental range was defined at the top by their optimal level, which they produced with contextual support, and their functional level, which they produced under ordinary, low-support conditions. With high support, children's answers became more complex by about a half of a level on the skill scale, on average. The increase in complexity following the support event was consistent across the large majority of children in the sample. After the initial trial or two of the posttest, most children showed a drop in performance, returning eventually to their pretest level. Approximately one fifth sustained their high performance throughout the posttest, showing robust knowledge that they could sustain once they understood the nature of the task and the expected answers.

One small surprise was that kindergartners and second-graders in the support condition improved approximately the same amount with high support even though the explanations modeled were farther from the pretest level of the kindergarteners. While we predicted that both groups would show improvement, we expected that the contextual support would prove more effective for the older children. Our findings suggest that the model provided, though quite complex, was within the developmental range of most of the kindergartners tested so as to have a similar effect to the second-graders on their performance.

Third, we found that children's responses to the support condition varied in organized and usually nonlinear ways. Rather than treating variation as noise or error, we examined it in a systematic way using individual growth modeling. This approach revealed that following the support event, half the children exhibited a cubic pattern in the complexity of their performance. That is, after the initial jump in complexity, their explanations systematically decreased and then increased and decreased again, as illustrated in Figure 3, Pattern A. It is as if the support event had an echo effect as children struggled to meet the complexity of the model answer in their own explanations. Twenty percent of the children did not show the echo effect but instead demonstrated a sharp drop in performance after one or a few trials performed at a high level; 12% exhibited a quadratic pattern (a few increased trials followed by a decrease; Figure 3 Pattern B) and 8% a linear decrease (one increased trial and then a sharp decrease for all remaining trials). Finally, one fifth of the children exhibited an increased complexity following support that persisted throughout the remaining trials (Figure 3, Pattern C).

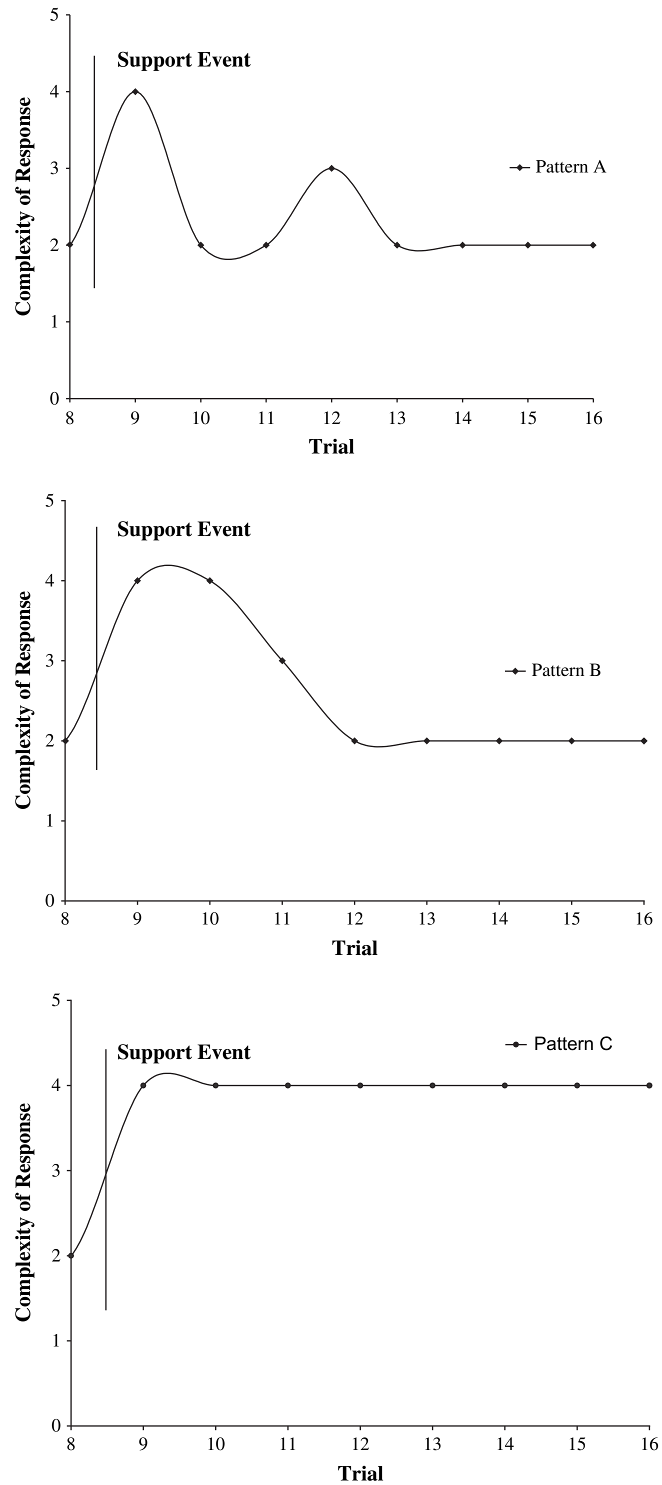

Fig. 3. Prototypical plots representative of the main patterns of children's performances following the support event.

A key question for future research is how students move from the transient effects of support shown by most of the children to the sustained performance shown by some of them.

Prior research has found that this process is slow and cannot be achieved quickly by simple instruction or intervention (Brown & Reeve, 1987; Fischer & Bidell, 2006; Fischer et al., 1993). One possibility is that in learning new skills, people use their performance under support to build a general sketch for the kind of skill they need to create for robust knowledge, which they can sustain without support. They can use this sketch to bootstrap themselves to build the new skills instead of merely groping without direction (Fischer & Bidell, 2006; Granott, Fischer, & Parziale, 2002). The process may be analogous to setting up an unconscious equation with various unknowns and then directing one's behavior to determine the nature of those unknowns. The high-level performance with support provides the sketch or outline to guide learning toward robust knowledge. These results indicate that the structure of children's knowledge is not static or definable by a single estimate, but variable and dynamic, dependent on many factors, one of the most important of which is support.

One key to unpacking the process of moving from transient to robust knowledge is analysis of individual differences in learning patterns. Only a few studies have examined the impact of individual differences on children's responses to support or scaffolding (Day & Cordon, 1993). Factors such as background knowledge, skill level in other domains, verbal intelligence, and socioeconomic status are likely to mediate the rate and pattern of learning in both support and nonsupport conditions. The variability in performance requires multifactor dynamic models of learning and development (Fischer & Bidell, 2006; van Geert, 1998).

Informing Previous Research on Children's Concepts About Buoyancy

With regard to complexity of performance, our findings support prior research and go beyond it to characterize the dynamic effects of contextual support. Both kindergarteners and second-graders showed a sharp difference between low- and high-support conditions, with findings of most prior research corresponding to the results for low support (Laurendeau & Pinard, 1980; Piaget, 1930/1960). On average and without support, kindergartners tended to give simple answers that focused on the identity of the object (Step 1, "The ball floats because it is a ball"), while second-graders tended to give answers that focused on object characteristics more relevant to the concept of bouyancy (Step 2, "The ball floats because it is light"). With support, children's answers were more complex. Kindergartners tended to give answers near Step 2, while second-graders tended to give answers near Step 3 ("The ball floats because it is small and light").

The findings also fit with prior research on the relation between correct predictions and explanations (Esterly, 2000; Kohn, 1993). Although explanations are related to correctness in the big picture of development, these two aspects of performance seem to operate independently under conditions of targeted support. We found no effect of complexity support on predictions, as well as little or no difference between kindergartners and second-graders in their rate of correct judgments. Across all trials, the rate of correct predictions were relatively high, even when the complexity of explanations was low. The high level of correct predictions was surprising, especially for the kindergarteners, given that the children were from urban environments and came mostly from families that were not highly educated.

Limitations of the Current Research

There are three main limitations to the present study. First, we did not collect concurrent data on children's understanding of other areas of science. Had we collected such data, we might have been able to predict other reasons why some children increased in their complexity, whereas others did not. Although our use of everyday objects might be seen as a limitation, we purposefully selected such objects to make the study more naturalistic and engaging for the children. Whether the use of specially constructed objects would have altered the results remains an empirical question. Finally, to maximize children's involvement and keep the situation similar to natural environments such as homes, classrooms, and children's museums, we allowed children to select objects that they wanted to test rather than presenting them in a prearranged counterbalanced order.

CONCLUSIONS

The findings begin to specify the effects of contextual support on performance in 5- to 8-year-olds, and they fundamentally inform both cognitive theory and educational practice. Specifically, contextual support creates a major spurt in complexity of performance, but for most students, the effect is transient, dissipating either quickly after one trial or gradually over several trials (linear, quadratic, and cubic growth patterns). A few students, on the other hand, spurt to complex performance and sustain that high-level skill over many trials. Based on previous research, this set of patterns seem to be general across skills and ages, and so are fundamentally important for science and practice. Though still needing further research, these data/analyses suggest that people may use their transient high-level supported performance to create a sketch or shell to guide their learning as they move toward more robust knowledge.

Cognitive science must treat competence as dynamic rather than fixed and analyze how students move from transient to robust knowledge. In education, teachers and schools must treat skills as dynamic in both assessment and instruction. For example, they need to assess students' performance in supportive situations separately from their robust knowledge. They need to build teaching and curriculum around the process by which students move from transient knowledge under high support toward robust knowledge that requires no support. For both cognitive science and education, analyzing the dynamics of support will require bringing together multiple individual factors such as background knowledge, skill level in other domains, learning style, socioeconomic status, and verbal intelligence. With analyses of such converging factors, scientists and educators can build dynamic models of the processes of support in learning and the movement from transient to robust knowledge.

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