Collaboration and the importance for novices in learning java computer programming

Carole A. Bagley, Ph.D.
University of St. Thomas
2115 Summit Ave. OSS 416
St. Paul, MN 55105
651-962-5397
cabagley@stthomas.edu

C. Candace Chou, Ph.D.
University of St. Thomas
1000 LaSalle Ave., MOH 217.
MPLS, MN 55403
651-962-4814
ccchou@stthomas.edu

ABSTRACT
The authors propose that a correlation exists between collaboration and success by novices when learning computer programming. Research in an introductory course was conducted that focused on answering several questions: At what time in their learning java programming and algorithmic problem solving, would a student benefit best by collaboration? At what time during the problem solving process would the learner benefit greatest by collaboration? Would the student benefit greater by collaborating with 1 student in the class, a group, or an expert mentor/coach? What cognitive and affective strategies are used during various types of collaboration? Does collaboration increase problem solving performance by females?

This research will advance fundamental knowledge of teaching and learning of computer science. It will further the understanding of problem solving and strategies used in learning computer programming and whether collaboration is important.

Categories and Subject Descriptors
K.3.1 [**Computer Uses in Education**]: Collaborative learning; K.3.2 [**Computer and Information Science Education**]: Computer science education

General Terms
Algorithms, Design, Human Factors, Languages

Keywords
Pedagogy, CS1/2, CS Ed Research, Collaboration, Gender, Cognitive strategies, Affective strategies, Problem solving

1. INTRODUCTION
A technology-literate population is a critical national asset in the global market, and it is necessary for every person in the U.S. to "be all they can be, technically" [5] [9]. The cold facts are that few U.S. citizens are selecting technical careers and females are selecting these careers in far fewer numbers.

The number of females who work as systems analysts, programmers, and post-secondary computer science teachers has decreased substantially [9]. The number of females pursuing computer science degrees has declined considerably in the last twenty years [9]. In fact, the widely cited statistics from the "The Incredible Shrinking Pipeline Unlikely to Reverse" [4], indicate that the percentage of females entering computer science programs and careers in the US has declined precipitously during the past decade and suggest this is unlikely to change.

Impersonal environments and guarded behavior, and the creation and maintenance of informal hierarchy resulting in competitive behaviors seem to prevail in computer science classrooms. These communication patterns lead to a defensive climate, characterized by competitiveness rather than cooperation; judgments about others and superiority; and neutrality rather than empathy. Collaborative and cooperative learning environments are effective teaching strategies for technology learning by all learners because they promote learning through social interaction with others. Providing role models and mentors for female and minority students is another way to increase their interest in technology careers [3]. Recognition of the different approaches to learning by gender may also encourage the participation of female students.

2. LITERATURE REVIEW
Problem solving is an important part of learning computer science, requiring the learner to "use" information and knowledge and requiring one to use "critical thinking skills". Deek [6] reviewed twelve different models of problem solving developed this century. Principal among these is Polya's [10] famous work on problem solving. The problem solving taxonomy developed by Zanzali [18] for mathematics, based on Polya's work, provides problem solving mastery levels that the authors adapted to the learning of computer programming and used to determine important times when collaboration is helpful.

Deek and McHugh [6] describe the computer programming problem solving process as a 6-step model: Formulating the problem, Planning the solution, Designing the solution, Translation, Testing, & Delivery. Deek and McHugh write that programmers must develop skills that include: learning the language, composing new programs, comprehending, reusing & integrating existing programs, debugging, testing, modifying, & documenting the programs they write. These are cognitive tasks related to language and require knowledge of the syntax & semantics of the programming language [12]. Other cognitive problem solving tasks (problem understanding, analysis, solution design) require domain, strategic & tactical knowledge, as well as practical knowledge of the programming.

ITiCSE Conference'07, Dundee, Scotland.

What does a successful problem solver know that an unsuccessful problem solver does not know [7]? First, research on problem solving [7] [14] [15] points to the crucial role of domain-specific knowledge, that is, to the problem solver's *skill*. Unfortunately, mastering each component skill is not enough to promote non-routine problem solving. Students need to know not only what to do, but also when to do it. Therefore, a second ingredient, suggested by research on intelligence [15] and on the development of learning strategies, is the ability to control and monitor cognitive processes [7]. This aspect of problem-solving ability is the problem solver's *metaskill or Meta-cognition*. A third prerequisite for successful problem solving [11] suggests that the problem solver's *will* is a significant factor.

Problem solving, when done as a collaboration among two or more individuals may increase learning of java programming and problem solving skills, however, little research has investigated this interaction. In a classic study of group IQ, conducted by Williams and Sternberg [17], social effectiveness was a better predictor of group performance than individual IQ's.

The authors believe that stronger problem solvers can be developed through collaboration rather than working alone and that this will benefit all learners including men, women and minorities. A study of group processes of professional programmer teams has shown collaboration and communication among team members to be especially heavy during the planning and requirements analysis phases of problem solving, less frequent during design and coding, and more frequent again during the deployment and maintenance phases [8] [16]. Is it possible that the use of collaboration by novices in learning programming and problem solving processes mirrors those experiences of professional programmer teams? Is it possible that novices benefit by collaborating at some stages of the computer program problem solving process more than others?

3. PROBLEM STATEMENT

Communication and problem-solving skills have become increasingly important skills in the changing economy and work place [13]. Mayer [7] examined the role of cognitive, metacognitive, and motivational skills in problem solving. He concluded that when a student fails to solve a problem, lack of knowledge is not always the source of failure. Metacognitively, a student can be highly knowledgeable but does not know how to devise, monitor, and revise a solution plan. On the motivational side, a student can also fail because of a lack of confidence or interest.

Reflecting on communication and collaboration practices used in the context of problem solving in the classroom is the first step to changing the culture and appeal of computer science. This must begin in the lower division courses.

3.1 Research Questions

Basic concepts of problem solving and algorithmic design have been taught during the conduct of this research. **Four stages of learning** during the course culminate with the ability to write a program that requires:

Stage 1) sequential programming & problem solving concepts

Stage 2) planning/use of conditional & repetition algorithms

Stage 3) methods & module decomposition

Stage 4) transfer of learning to a more complex program

Each assignment (stage) required the students to use the following **six problem-solving steps**:

Step 1) conceptualization/ brainstorming and formulating the problem and requirements

Step 2) plan the system solution

Step 3) design each component/module and walkthrough

Step 4) detailed coding and preliminary testing

Step 5) full scale testing and revision

Step 6) documentation and presentation

The following research questions were used to structure the experiment and will be answered in Section 5:

1) At what **stage (1-4)** in their learning java programming, would a student benefit best by collaboration?
2) At what **step (1-6)** in the algorithmic problem solving/software engineering process would a student benefit by collaboration?
3) Would a student benefit greater by working by them self or in collaborating with 1 student in the class, a group, or an expert mentor/coach?
4) Do students show significant cognitive gains when engaged in a collaborative learning environment and which cognitive strategies are enhanced during the collaborative problem solving?
5) Do students show significant affective gains when engaged in a collaborative learning environment and which affective strategies are enhanced during the collaborative problem solving?
6) Is collaboration more important for males or females?

4. METHODOLOGY/DATA COLLECTION

Over three semesters, 69 students were randomly assigned to one of four different group types and worked in this group during class and while completing lab work and 9 assignments outside of class. The group types were: self, pair, group, or mentor. Students were randomly assigned to eliminate prior experience and GPA as conflicts. Each group type began working together after Asg. 1 which was approximately 2 weeks into the course.

The **self** group type worked independently. The **pair** groups were two students from the same class. **Groups** collaborated with a team of 3-4 students. **Mentor** groups used a mentor/expert to guide the student. The self & mentor group types consisted of 6 groups each (1 student/group) with the pair group having 12 groups (2 students/group for total of 24 students) and the group type having 11 groups (3 students/group for total of 33 students).

Students who completed the java programming course were trained as mentors to work with the mentor group students.

The research employed both quantitative and qualitative methods. SPSS was used to determine the significant cognitive and affective strategies developed by the students and the impact on collaboration. The cognitive coding scheme was based on Bloom [2] and Deek and McHugh [7]. The affective coding scheme was based on research by Anderson and Krathwohl [1].

The quantitative data included the Collaboration Satisfaction questionnaire (http://personal.stthomas.edu/cabagley/ITiCSE/CollaborationSatisfactionSurvey.html), the Collaboration and Java programming questionnaire (http://personal.stthomas.edu/cabagley/ITiCSE/CollaborationandJavaProgramming.html) and the instructor's grading based on the assignment rubric. Each student completed the two questionnaires at four stages (1-4) to determine the perceived effect collaboration had on the student's learning and motivation, the student's perception of when collaboration was most important, and to determine cognitive and affective strategies that were enhanced by collaboration. Females in all groups were analyzed independently to determine whether collaboration had a significant effect.

The qualitative data gathered at four stages included: student reflections, interviews, and instructor reflection.

5. RESULTS

5.1 At what problem solving step and stage in learning is collaboration most important?

The mean rating over all steps of the problem solving process (steps 1 – 6) indicated that stage 4/asg9 was the most important time to collaborate (stage 1: M = 7.13, stage 2: M = 7.29, stage 3: M = 6.93, stage 4: M = 7.77).

The mean rating for step 1 (conceptualization/brainstorming and formulating the problem & requirements) is highest (M=8.04), indicating it is more important to collaborate at the first step when beginning an assignment. The mean is lowest at step 6 (M=5.39) indicating it to be a less important time to collaborate.

Table 1. Importance of Collaboration Means

Stage / Asg #		Problem Solving Step						
		1	2	3	4	5	6	Over - all
1 / 2	Mean	8.44	7.50	6.61	7.22	7.44	5.56	7.13
2 / 4	Mean	7.94	7.69	7.94	7.50	7.44	5.25	7.29
3 / 7	Mean	7.35	7.12	7.88	7.00	7.18	5.06	6.93
4 / 9	Mean	8.39	8.17	8.61	7.83	7.94	5.67	7.77
TTL	Mean	8.04	7.62	7.75	7.39	7.51	5.39	

Step 3 in the problem solving process (design each component/ module) showed a significant difference in mean across all 4 stages of learning, rating the importance of collaboration (1-10 scale with 1 being least important) on different assignments (stage 1/asg 2, stage 2/asg 4, stage 3/ asg 7 and stage 4/asg 9), $F(3, 65)=2.98$, $p< 0,05$. The mean rating for stage 1/asg 2 (M= 6.61, SD= 2.12) was significantly lower than stage 4/ asg 9 (M=8.61, SD=1.5). This indicated that students found it more important to collaborate at step 3 of the problem solving process on a complicated program (stage 4/asg 9) than on an easier assignment that was completed earlier in the course.

Although there was no **significant** difference between female and male students, female students did generally rate the importance of collaboration higher than male students.

5.2 Grouping type and greatest benefit?

Students in groups reported working fewer total hours (M= 5.6, SD= 2.53) than other groups, $F(3, 64)=7.54$, $p< 0.001$). Students spent fewer hours working alone when they worked in a group (M= 2.67, SD= 2.63) or with pairs (M= 2.55, SD= 3.4), $F(3, 66)=18.64$, $p<0.001$. Students reported a higher course grade ($p< 0.05$) when working in pairs (M=2.63, SD= 1.36) and mentors (M= 0.80, SD= 0.45), $F(3,68)=7.54$, $p<0.001$.

Table 2. Grade Average and Mean Work Hours by Groups

Grouping		Grade	Total hours	Work together	Work alone
self	Mean	4.00	7.6667	.0000	8.0000
pair	Mean	2.63	8.3200	5.3704	3.0000
group	Mean	3.51	5.6357	2.9643	2.6714
mentor	Mean	.80	12.900	1.1000	11.800
Total	Mean	3.03	7.2463	3.6848	3.8214

Table 3. Course Grades

Grade	A	A-	B+	B	B	B-	C+	C
Code	1	2	3	4	5	6	7	8

Female students (M=9.9) spent more hours working in groups or alone than male students (M=6.45), $F(1, 66)=9.55$, $p<0.1$.

5.3 Cognitive strategies

Questionnaires, course grade & instructor observation indicated gain in factual, conceptual, procedural knowledge & metacognition. Use of specific strategies was different between groups.

5.3.1 Factual Knowledge

There was a difference between groups (self, pairs, groups, and mentor) over all four stages of learning for questions 7 & 8 from the Collaboration and Java programming questionnaire. For question 7 (I used a template without changes to write my program), pairs (M=3.83) $F(3, 64)=6.05$, $p=0.001$, reported the highest means. Students working alone showed a low mean (M=1.29) and likely didn't rely on factual knowledge. Regardless, overall mean scores is low (M=4.47), indicating most students did not rely on a template.

For question 8 (I use a template with minor changes), there was a significantly higher mean $F(3, 65)=3.79$, $p<0.05$, for students with a mentor (M=7.4) & groups (M=7.2).

Question 9 (I used a template but went beyond) showed a higher mean score (M=7.5) between different groups indicating most used planning and problem solving skills.

Table 4. Factual Knowledge Mean Scores by Grouping

Grouping		Q7	Q8	Q9	Q10
self	Mean	1.29	5.29	6.57	1.00
pair	Mean	3.83	4.92	6.65	5.31
group	Mean	5.82	7.21	8.06	2.61
mentor	Mean	3.00	7.40	9.00	1.00
Total	Mean	4.47	6.23	7.50	3.21

5.3.2 Conceptual Knowledge

There was a significant difference between different groups for questions 11, 18, & 19 from the Collaboration and Java Programming questionnaire. The mean scores for question 11 (I learned by memorizing the new concepts) was the lowest of all conceptual knowledge strategies (M=4.24). Students in groups reported significantly higher mean scores (M=5.48) than other groups, $F(3, 64)=7.46$. It could mean that students come to the group discussion with conceptual preparation.

For question 18 (I created multiple algorithms), students in groups show significantly higher mean scores (M=6.36) than other groups, F(3, 64)=3.37, p<0.05, therefore, groups are more inclined to try out multiple algorithms.

For question 19 (I was able to present the project orally), students in groups showed significantly higher mean scores (M=6.56) than other grouping types, F(3, 59)=3.89, p<0.05. This indicated that groups were more likely to be confident in presenting orally.

Table 5. Mean Scores of Conceptual Knowledge by Group

Grouping		Q11	Q18	Q19
self	Mean	2.17	3.00	3.83
pair	Mean	3.38	5.63	4.91
group	Mean	5.48	6.36	6.56
mentor	Mean	2.60	4.40	1.00
Total	Mean	4.24	5.66	5.46

Although, there was no significant difference with any of the grouping types for question 17 (I checked requirements and adapted the algorithm continuously), there was a gender difference. This indicated that females were more likely to believe in the importance of checking requirements & revising algorithms.

Table 6. Mean scores of conceptual knowledge by gender

Gender		Q17
male	Mean	7.02
female	Mean	8.94
Total	Mean	7.47

5.3.3 Procedural Knowledge

There was a significant difference among groups for questions 27, 28, & 29 from the Collaboration and Java programming questionnaire. For question 27 (I performed frequent checks), groups have higher means (M=9.09) when performing frequent checks to make sure that they are moving in the right direction, F(3, 64)=9.28, p<0.001. For question 28 (I tried different strategies), groups (M=7.39) demonstrate a higher rate in trying out different strategies before solving a problem, F(3, 64)=6.41, p=0.001. For question 29 (I hypothesized and observed the effect), groups again (M=7.42) show a higher rate in coming up with a hypothesis & observing its effects, F(3, 64)=4.59, p<0.01.

There was a gender difference for question 26 (I analyzed the worked samples) indicating that regardless of grouping, females believe it is important to analyze & compare the problem and solution to worked samples.

Table 7. Mean Scores of Procedural Knowledge by Group

Grouping		Q26	Q27	Q28	Q29
self	Mean	8.50	5.33	4.00	6.00
group	Mean	7.91	9.09	7.39	7.42
mentor	Mean	8.60	5.80	4.40	3.40
Total	Mean	8.01	7.82	6.13	6.46

Table 8. Mean Scores of Procedural Knowledge by Gender

Gender		Q26
male	Mean	7.71
female	Mean	9.00
Total	Mean	8.01

5.3.4 Metacognition

Student rating of the strategies employed in the metacognition category is high. It indicates that java programming requires a fair amount of planning and testing. For question 31(I seek information from others and brainstorm to solve the problem), students in pairs (M=8.17) or groups (M=8.39) show a significantly higher rating, F(3, 64)=6.19, p=0.001. For question 32 (I devise strategies for problem-solving), self, pairs, or groups have significantly higher ratings. For question 34 (I conduct a full-scale testing and created new/better solution), students working by themselves (M=8.33) have a significantly higher rating, F(3, 64)=6.13, p=0.001.

There was a significant difference between gender (females: M=8.94, males: M = 7.19, p = .01) for question 34 indicating that females believe testing produces a better solution.

Table 9. Mean Scores of Metacognition by Group

Grouping		Q31	Q32	Q34
self	Mean	4.83	8.17	8.33
pair	Mean	8.17	7.67	7.71
group	Mean	8.39	8.18	8.03
mentor	Mean	6.80	5.40	3.40
Total	Mean	7.88	7.79	7.60

Table 10. Mean Scores of Metacognition by Gender

Gender		Q34
male	Mean	7.19
female	Mean	8.94
Total	Mean	7.60

5.4 Affective strategies: Impact of collaboration on learning and motivation

The results from the Collaboration Satisfaction questionnaire, indicated that pairs (M= 4.83, SD=0.37) and groups (M= 4.54, SD= 0.7) believe that collaboration is important in increasing learning and motivation. Students in the self category reported a lower mean score (M=1.3, SD= 0.58). The impact of grouping in the ranking of learning and motivation is significant (p< .001). There was no significant gender difference.

Table 11. Learning and Motivation Means by Grouping

Grouping		learning	motivation
self	Mean	1.33	1.00
pair	Mean	4.83	4.93
group	Mean	4.54	4.66
mentor	Mean	3.75	4.50
Total	Mean	4.47	4.59

There was a significant difference among groups for questions 36, 37, 38, & 40 from the Collaboration and Java programming questionnaire. Students in pairs or groups expressed strong agreement in listening to partner(s) (#36) and talking about concepts/facts related to the problem (#37), p<0.001. Groups showed higher means in debating with respect and valuing their contribution (#38), p<0.001. Groups and with a mentor indicate a significantly higher agreement in buying into the solution of the problem and believing it was the best solution (#40).

Table 12. Mean Scores of Affective Strategies by Groups

Grouping		Q36	Q37	Q38	Q39	Q40
self	Mean	3.20	3.17	2.40	8.67	4.80
pair	Mean	9.29	8.50	6.29	8.38	6.65
group	Mean	8.58	8.55	8.55	8.61	8.21
mentor	Mean	6.33	7.25	6.33	6.40	8.80
Total	Mean	8.32	7.97	7.14	8.37	7.45

5.5 Collaboration and gender differences

Although there was no significant difference, the female means indicate that they rate the importance of collaboration higher. Although only 20-25% of the students are female, the course mean grades for females are higher. Those students working in pairs or with a mentor received higher overall course grades regardless of gender. Females spent a significantly greater amount of time than males when working in a group or alone.

Table 13. Grade Average and Mean Work Hours by Gender

Gender		Work together	Work alone	Grade	Total hours
Male	Mean	3.3472	3.2500	2.96	6.4953
Female	Mean	4.9000	5.7500	3.24	9.9000
Total	Mean	3.6848	3.8214	3.03	7.2463

6. CONCLUSION

Collaboration is an important pedagogy to use in teaching computer science and in performing java programming. This study indicates that the more complex a problem, the greater is the importance of collaboration. The most important time for collaboration in the problem solving/programming process is at steps 1(brainstorming and formulating the problem) and 3 (designing individual components/modules).

Groups tried out multiple algorithms and frequently reflected on a variety of strategies. Course grades were significantly highest for pairs or those working with a mentor regardless of gender. Therefore, can the extra time spent by groups be justified?

Conceptual knowledge was higher for groups in understanding the importance of coming to the group with the concepts prior to discussion and experimentation of multiple strategies. Groups were more confident in presenting orally.

Procedural learning was significantly highest for groups particularly in performing frequent checks, trying out different strategies and hypothesizing and watching the effects. Females showed a significantly high level of these procedural strategies.

Metacognitive strategies of brainstorming and devising strategies in pairs were significantly high. Females showed a significant difference in creating a better solution after performing testing.

The affective characteristics of motivation to learn and the belief that learning increases with collaboration were stronger in groups. There was no significant gender difference.

7. REFERENCES

[1] Anderson, L.W., & Krathwohl (Eds.) *A Taxonomy for Learning,Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. NY: Longman, 2001.

[2] Bloom, B., Englehart, M. Furst, E., Hill, W., & Krathwohl, D. *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain*. New York, Toronto: Longmans, Green, 1956.

[3] Brown, B. L. Women and Minorities in High-Tech Careers. ERIC DIGEST NO. 226, 2001.

[4] Camp, T. *Women in computer sciences Reversing the trend*. http://www-2.cs.cmu.edu/~women/resources/aroundTheWeb/hostedPapers/Syllabus-Camp.pdf, 2001.

[5] Datz, T. "Degrees of Change" CIO Magazine 15 October. www.cio.com/archive/101504/school.html, 2004.

[6] Deek, F.P., & McHugh, J. Problem Solving and Cognitive Foundations for Program Development: An Integrated Model. *Proceedings of the Sixth International Conference on Computer Based Learning in Science (CBLIS),* (pp. 266-271). Nicosia, Cyprus. http://cblis.utc.sk/cblis-cd-old/2003/2.PartA/Papers/ICT/Deek.pdf, 2003.

[7] Mayer, R. Cognitive, metacognitive, and motivational aspects of problem solving**.** Instructional Science, 26, 49–63. Kluwer Academic Publishers. The Netherlands, *http://www.colorado.edu/physics/phys4810/phys4810_fa04/4810_readings/mayer.pdf*, 1998.

[8] Nosek, J.T. The Case for Collaborative Programming. By J. T. Nosek. Communications of the ACM. Volume 41. Issue 3. Pages 105-108, 1998.

[9] NSF. *The Science and Engineering Workforce :Realizing America's Potential*, Rpt.14.Arlington,VA:NSF. www.nsf.gov/nsb/documents/2003/nsb0369/nsb0369.pdf, 2003.

[10] Polya, G *How to Solve It: A New Aspect of Mathematical Method,2nd Edition.* Princeton, NJ:Princeton Press, 1957.

[11] Renninger, K, Hidi, S. & Krapp, A., eds. *The Role of Interest in Learning and Development.* Hillsdale, NJ: Erlbaum, 1992.

[12] Shneiderman, B., (1980) Software psychology: Human factors in computer and information systems. Cambridge, MA: Winthrop Publishers.

[13] Secretary's Commission on Achieving Necessary Skills (SCANS). What work requires of schools A SCANS Report for America 2000. Washington DC: US Labor Department. http://wdr.doleta.gov/SCANS/whatwork/whatwork.pdf.

[14] Smith, L.B. The socialization of females with regard to a technology-related career. *Meridian: A Middle School Computer Technologies Journal, 3(2).* Retrieved 1/05 from: http://www.ncsu.edu/meridian/sum2000/ career/, 2000.

[15] Sternberg, R. & Frensch, P., eds. *Complex Problem Solving: Principles & Mechanisms.* Hillsdale, NJ: Erlbaum, 1991.

[16] Williams, L., Kessler, R. Pair Programming Illuminated. By L. Williams, R. Kessler. Addison Wesley, 2003.

[17] Williams, W., & Sternberg, R. J. Group intelligence: Why some groups are better than others. *Intelligence*, 12, 1988.

[18] Zanzali, N. et.al. Evaluating the levels of problem solving abilities in mathematics. Retrieved January 10, 2005, from http://math.unipa.it/~grim/Jzanzalinam.pdf, 2004.