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ABSTRACT

A fundamental challenge to computer science education is the difficulty of broadening participation of women and underserved communities. The idea of game design and game programming as an activity to introduce children at an early age to computational thinking in a motivational way is quickly gaining momentum. A pedagogical approach called Project First has allowed the Scalable Game Design project to reach a large group of middle schools students including a large percentage of female (45%) and underrepresented (48%) students. With over 4000 students in inner city, remote rural, and Native American communities Scalable Game Design has investigated the impact of pedagogical approaches employed by teachers such as mediation and scaffolding onto students' levels of interest. Findings suggest strong gender effects based on classroom scaffolding approaches. For instance, girls are substantially less likely to be motivated through scaffolding based on direct instruction. Conversely, guided discovery scaffolding approaches are highly motivating to the point where they can even overcome other negative predictors such as small girls to boys class participation ratios. This paper introduces the project, discusses different scaffolding approaches and presents data connecting gender specific motivational levels with scaffolding approaches.

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: Computers and Information Science Education – *a ca a ac , c .*

General Terms

Measurement, Experimentation, Human Factors.

Keywords

Student interest, guided discovery, teacher-directed instruction.

1. Introduction

One of the central questions still being asked by computer science educators is whether instructional experiences should start with programming techniques stressing notions of program control (e.g., loops, if-then-else statements, etc.) before moving to the design of projects, or the other way around. Of course, while some knowledge of programming methods is required to design interesting programs, what is the differential impact on student motivation of more a directive approach compared to a guided discovery approach? Results from the implementation of a game and simulation design curriculum suggest that instruction that incorporates a more guided discovery approach may address an apparent motivation gap that we identified between middle school girls and boys.

The Scalable Game Design project [1] context in which this study took place involved the implementation of instructional units to support student design of games and science simulations using AgentSheets [2], as a way to motivate student interest in computer science courses and careers. To broaden the participation of middle school, we recruited teachers and schools in diverse settings, such as urban, remote rural, and Native American communities including school serving significant proportions of low income students. Embedded in existing computing education and STEM courses, the project curriculum introduces students to CT through game design and then advances to STEM simulation design. Teacher participation was supported by a two-week summer institutes prior to implementing game and simulation design units.

High levels of interest by teachers resulted in rapid project diffusion, as the proposed goal of reaching 1120 students in 3 years was exceeded in the first implementation semester and is estimated to reach over 5000 students by the end of the project.

The integration of the curriculum into existing courses resulted not only in very high participation by female (45%) and underrepresented minority students (48%) but also high levels of motivation, as expressed by students' interest in taking another game design class: 74% of boys, 64% of girls (100% for some schools); 71% of white, 69% of minority students.

However, further analysis of student motivation with respect to gender ratios and the manner in which teachers implemented design units revealed emergent factors influencing student interest. This paper outlines the relationship of these factors and the potential contribution of a pedagogical theory of broadening student participation in K-12 computer science education.

2. Conceptual Framework

Improving students' interests in computer science education will require different approaches than the current set of middle grades options where students are exposed to business software and Internet use. Problems with the computer science pipeline extend into US high schools that typically offer Advanced Placement (AP) courses to represent the CS discipline. This type of curriculum is usually focused on programming, and fails to provide motivating applications. Courses of this nature do not attract many students and are even less successful in attracting women and minorities [3]. Even though there has been a modest increase in CS majors since 2009 [4], the rapid decline in student interest over the past decade leaves the number of CS majors at half the level of its peak in 2004. In spite of the recent national attention given to STEM education, computer science is rarely included as part of the national discourse. Fortunately, curricular responses to this *C E ca P b*[1] are already in play [5]. However, because of the systemic nature of the problem a revision to curriculum will be a necessary but insufficient response. We would argue that a renewed vision for computer science pedagogy may be a more critical part of the solution to the problem.

Our proposed vision for CS pedagogy, focuses on the differences between "our project-first" and "more traditional principals first" approaches. Our pedagogical approach allows students to learn the necessary CT principles just-in-time. The fundamental idea of the Project-first approach can be illustrated through what we call the *Z P a F* (ZPF), which combines Csikszentmihalyi's notion of Flow [6] with Vygotsky's notion of the Zone of Proximal Development (ZPD) [7]. Flow is an ideal condition for learning, and illustrates the importance of attending to the affordances and limitations of particular forms of mediation, as well as the need for social and technical scaffolding to advance learning. The ZPD can be understood as an orchestration of participation in a rich set of carefully designed practices where forms of assistance and tool use are strategically employed.

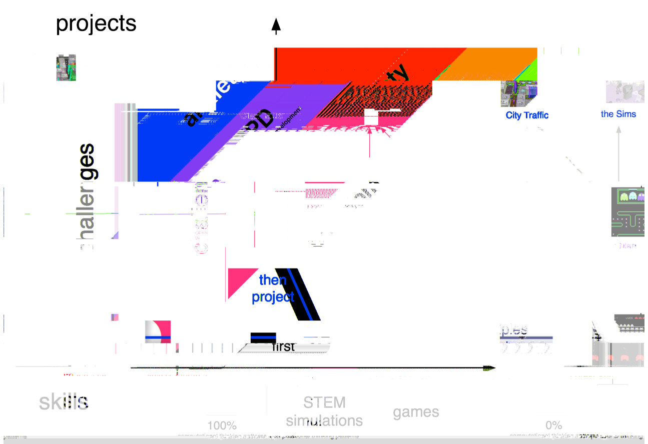

Figure 1. The Zones of Proximal Flow, a combination of Vygotzky's Zone of Proximal Development and Csikszentmihalyi's Flow.

In the *Z P a F* diagram in Figure 1, the horizontal axis represents students' computational thinking (CT) skills and the vertical axis represents the level of the design challenge that would be intrinsic to a certain game or STEM simulation. CT skills are measured through a Computational Thinking Pattern Analysis (CTPA), which utilizes principles of latent semantic analysis to identify programmed computational thinking patterns [ref]. As student acquisition of skills advances in response to the challenges, an ideal path in the flow region would progress from the origin to the upper right.

[1] Defined here as the systemic challenge to improved computer science education. With all due respect, we acknowledge the similarities between the Computer Education Problem and Jim Kaput's [8] articulation of The Algebra Problem, "...the intolerably poor outcomes of our highly dysfunctional, late, abrupt, isolated, and superficial approach to school algebra, and our collective inability to move beyond it." (p. 2).

Within this diagram, pedagogical approaches can now be described as instructional trajectories connecting a skill/challenge starting point (A) with destination point (B) in the Zones of Proximal Flow diagram. In many traditional CS education models, a *c -* approach would introduce students to a number of concepts such as AI search algorithms that may, or may not, be relevant for future projects. At some later stage, students receive the challenge of making a project such as a Pacman-like game.

The acquisition of skills without the context of concrete challenges is not a bad pedagogical model, especially at the undergraduate CS level, but it runs the risk of seeming irrelevant, hence boring, for a broader audience of younger students if it does not go hand-in-hand with project based approaches [9]. This assertion is consistent with the Flow model and with our own observations in classrooms. Instead of decoupling the acquisition of principles and the applications of these principles to a project, the project-first approach combines *- - CT ac* with *a ca* to produce a tangible artifact.

This project-first approach allows students with less experience and expertise to engage in practices and use tools otherwise not generally available to them. In restructuring computing education in ways that ratchet up the possibilities of zones of proximal flow to emerge, instances of unrealized learning will be minimized. The navigation of the skill/challenges space can be supported by teachers through different scaffolding approaches discussed in the next two sections.

2.1 Teacher-Directed Instruction

Teacher-Directed Instruction (direct instruction) is an approach where scaffolding is oriented toward an adult-defined endpoint or goal and, thus, provides limited opportunities to draw on students' repertoires of practice, or the cultural and knowledge toolkit that students develop across their learning trajectories. In a number of instances, the scaffolding can take on a form of hypermediation [10] in which excessive, non-strategic, and unnecessary assistance impedes rather than supports the learning goal. Teachers might use online tutorials in a lockstep fashion with all students expected to proceed together one step at a time to maintain control of the classroom. Rigidly following a tutorial with no room for deviation not only affects levels of engagement and motivation, but also student ownership, as they have little opportunity to embellish or personalize their game or simulation.

The result is a collection of practically identical artifacts for which there is no significant degree of ownership for students. This type of scaffolding may be good for introduction of something new to novices in the form of explicit instruction cases where game design is used in non-elective classes and where student's background and interest may vary widely or in classrooms with a large numbers of students and short class periods. In other words this can still be appropriate when game design is used in non-elective classes, or classrooms with large numbers of students.

2.2 Guided Discovery

When scaffolding is implemented as guided discovery, that is, when forms and degree of mediation are regulated to provide just enough assistance to support students' mastery of CT concepts, students tend to remain in the flow zone. In line with the concept of the Zones of Proximal Flow, the instructional trajectory organizes students' present activity in ways that build future psychological functions [11], including computational thinking. Instead of focusing on prescriptive steps explaining how to use the tool, teachers set more general goals for building the same game, but include discussions of why and how something should be done. Guided discovery still includes bits of formal instruction, but teacher regulation of mediation provides students more freedom to explore design options. Students' ability to personalize their design contributes to student ownership, which in turn could bolster levels of motivation.

3. Method

The project discussed in this paper was designed to investigate the potential impact on the IT workforce by stimulating interest in computer science at the middle school level. The main goal of this project is to increase opportunities for computer science education in public schools by motivating and educating students about computer science through game design starting at the middle school level. The strategy to maximize exposure includes the integration of computer science education into existing required courses such as exploratory wheels offered at most middle schools. Middle schools are excellent places for increasing and broadening the participation in computer science especially in regions where extracurricular options (e.g. after-school programs, summer camps) are financially problematic. To serve a wide spectrum of communities, we work with teachers and schools from urban, rural, suburban and remote/tribal regions. An important goal is to develop local resources and capacity for sustainability through the involvement IT students from local community colleges.

The primary evaluation question for the project was to monitor the impact of the game and simulation design experience on students' attitudes and dispositions towards computer-based design experiences, computer classes, and related future pursuits. Data were collected before the unit and after the unit, creating matched pre and post data for each student. For the purposes of this paper, we focus on the following data: 1) students' self-reported interest in similar experiences, 2) gender ratios for each teacher, and 3) observation of teacher practice.

3.1 Classroom Implementation

During the first year of the project, most teachers recruited into the project had not implemented a game design unit with their students. Teachers participated in a one-week summer institute to learn the interface and complete the activities they would use with their students (teacher data from summer institutes is reported elsewhere). These institutes and game design units stressed, implicitly at first, an approach that focuses immediately on making a complete game project. For instance, a teacher starting an activity would jump into making a game project with the student in the first hour of instruction even if the students had no background in programming whatsoever.

For the purposes of this report, it is important to recognize that the first year of the Scalable Game Design (SGD) project was the initial implementation of this software and design-oriented curriculum approach for most teachers. Issues encountered with the first implementation of a technology related unit could include problems with the school network, the need to debug and troubleshoot errors encountered during class, and teachers' limited awareness of potential student difficulties.

In Year 2 teachers were asked to extend the game design unit beyond Frogger, and have students design at least one more game (e.g., Pacman, Space Invaders) which required the programming of more advanced computational thinking patterns such as collaborative diffusion and choreography. Many of the teachers also implemented a unit in which students designed a math/science simulation (e.g., ant foraging, predator-prey ecosystem, etc). The duration between the administration of the pre- and post-unit surveys in Year 2 was, therefore, longer and the programming content was more sophisticated compared to Year 1.

After students completed their games they uploaded their program to a Scalable Game Design Arcade (SGDA). This student product repository allows students to play and download any uploaded game. Students can also post feedback to students who designed games, through comments and ratings. Teachers reported that the SGDA increased students' motivation since it allowed students to sharing artifacts through flow of inspiration principles [12].

3.2 Participant Demographics

During the Year 1 administration of the student motivation surveys, we collected 2,371 pre-unit responses and 1,299 post-unit responses. From the overall set we filtered out responses in which the student did not identify their teacher, reducing the respective sets to 2,070 pre-unit and 1,210 post-unit surveys. Using a simple matching of student initials, teacher, and birth date, we reduced the set of data to 894 matched pairs of pre and post unit responses (which is 43.8% of all pre-unit responses) from 13 middle grades teachers. Some teachers' data were not included here since they only administered the pre-unit survey and neglected to administer the post-unit survey before students moved onto a different course. In addition to these reasons, student numbers reported here do not represent all students who completed the Scalable Game Design units since participation in the administration of the surveys was also dependent on parental consent.

Of these 907 matched responses from the Year 1 administration of the student motivation surveys, 47.8% of the responses were from girls and 52.2% were from boys. With respect to self-reported ethnicity, 53.2% were White, 43.0% Hispanic or Latina/o, 13.5% Black, 10.5% Native American, and 6.2% Asian/Pacific Islander. This method of collecting ethnicity was aligned with the census and the new federal requirements from the U.S. Department of Education, therefore these percentages represent a duplicate count for some students. Students' grade level was 48% 6th grade, 29% 7th grade, and 22% 8th grade.

During the Year 2 administration of the student motivation surveys, by mid-February 2011 we had collected 1,241 pre-unit responses and 885 post-unit responses. Using a simple matching of student initials, teacher, and birth date, we reduced the set of data to 544 matched pairs of pre and post unit responses (which is 43.8% of all pre-unit responses). At the time the post-unit survey data were collected, teachers were still completing a unit and had subsequent iterations of implementing game design and STEM simulation units. During SGD planning meetings, we discussed and documented the observed practices of teachers and consequently developed a crude categorization scheme for pedagogy that identified teacher practice as primarily teacher-directed or guided discovery. In a few instances of limited classroom visitations, we used teachers' self-reported Lesson Log data and student products to determine the extent to which students were simply following instructions in related tutorials or if they were given opportunities to develop products demonstrating allowances for student creativity and ownership (e.g., opportunities to adapt methods or design their own game).

4. Results

As part of the student motivation survey given after students completed game and simulation design units, students were asked to respond to the statement, "I want to take another game design course." Students reported their interest using a four point Likert scale ranging from Strongly Disagree to Strongly Agree. Using the matched data from all survey responses, we disaggregated counts of boys and girls for each teacher and found the percentage of girls and boys who responded Agree or Strongly Agree to the statement. In addition to the total number of responses per teacher, we also found the ratio of girls to boys for each teacher.

4.1 Year 1 Comparisons

As shown in Table 1, responses for Year 1 data show the majority of girls and boys were interested in taking another game design class. The mean percent of students who were interested in taking another game design class, using teacher as the unit of analysis, was 65% of girls and 78% of boys (this difference in means was statistically significant at the $p < 0.05$ level). Out of 13 teachers, 11 groups of students showed a greater interest among boys, one teacher's group showed greater interest among girls, and one group showed equal interest between boys and girls. With respect to enrollment ratios per teacher, eight teachers had a boy-to-girl ratio favoring boys and five teachers gender ratio favored girls.

Table 1: Percent of boys and girls interested in taking another game design class by teacher, number of students, and ratio of boys to girls in Year 1 survey group.

TEACHER	GIRLS	BOYS		N	RATIO (G : B)
A	50%	71%		134	51 : 49
B	77%	91%		74	41 : 59
C	88%	90%		52	62 : 38
D	63%	77%		114	47 : 53
E	63%	94%		35	49 : 51
F	75%	65%		35	54 : 46
G	67%	86%		10	30 : 70
H	50%	57%		30	53 : 47
I	71%	80%		58	43 : 57
J	85%	85%		65	40 : 60
K	68%	71%		178	39 : 61
L	59%	64%		91	64 : 36
M	28%	80%		18	44 : 56
Average	65%	78%		894	

An interesting relationship that also emerged in the Year 1 data was found among teachers who had boy-to-girl ratios with large differences favoring boys (see last column for teachers B, G, I, J, K & M). Four of these teachers also had differences in student interest in future game design class favoring boys (i.e., B, G, I & M). This pattern suggested that student enrollment ratios could have a differential effect on student interest. Two other teachers in this group (i.e., K and J) also had enrollment ratios favoring boys without the same differences in interest.

Of the two teachers K and J, we observed that Teacher J demonstrated a guided discovery approach with students, which we surmised could be a possible factor in the negligible difference in interest between boys and girls (in spite of the 40:60 girl-to-boy gender ratio that would typically suggested a potential difference in interest favoring boys). Although we recognize that data for 13 teachers should be interpreted with caution, we continued to monitor this relationship in the Year 2 data.

4.2 Year 2 comparisons

In the second year of the project we continued to administer student motivation surveys to students before and after completion of a multi-week unit. In contrast to Year 1, the unit activities involved the design of one or more games and a STEM simulation during the 2010-11 school year. Typical simulations included a viral outbreak, a forest fire simulation, and predator-prey models. Similar to the Year 1 post-unit survey, students were asked if they wanted to take another game design course after completing the unit.

The same filtering and matching methods used with Year 1 data were applied with the Year 2 data, and any data entries that did not have a pre/post match were discarded. This reduced the set of all responses from 2033 combined responses to 1052 responses (i.e., 526 matched).

As with Year 1 results, as shown in Table 2 the majority of boys and girls in almost all classes were interested in taking another game design class (see Table 8). In contrast to Year 1 however, these differences in means (64% girls v. 74% boys) were not statistically significant.

Table 2: Percent of boys and girls interested in taking another game design class by teacher, number of students, and ratio of boys to girls in Year 2 survey group.

TEACHER	GIRLS	BOYS		N	RATIO (G : B)
N	44%	73%		152	36 : 64
O	67%	93%		24	38 : 63
P	71%	70%		37	46 : 54
Q	76%	86%		93	53 : 47
R	50%	50%		14	29 : 71
S	38%	57%		31	55 : 45
T	100%	67%		9	67 : 33
U	67%	86%		15	47 : 53
V	0%	82%		20	40 : 60
W	71%	88%		15	13 : 87
X	85%	90%		47	57 : 43
Y	100%	70%		12	17 : 83
Z	79%	75%		28	46 : 54
AA	52%	55%		29	38 : 62
Average	64%	74%		526	

Note: To protect teacher confidentiality teacher labels for Year 1 data do not correspond to teacher labels for Year 2 data.

In addition, the exclusion of one teacher (V) results in a mean difference of only 5% (69% girls v. 74% boys).

Out of data for 14 teachers, 9 groups showed a greater interest among boys, 4 groups showed greater interest among girls, and one class showed equal interest between girls and boys. The summary means combined with the distribution of suggests that Year 2 saw a greater balance in interest between boys and girls. Similar to Year 1 results, large differences favoring boys might be attributed to either a greater boy-to-girl ratio (e.g., teachers N, O, U, V, & W) coupled with over-reliance on direct instruction (e.g., teachers N and V). The influence of gender differences on students' continued interest appears to be ameliorated by teachers who demonstrated pedagogical approaches characterized by guided discovery (i.e., teachers R, Z, AA).

Figure 2 offers a visual comparison of gender differences in student interest in taking similar courses. The results from Table 2 appear as a double bar graph for each teacher. It is worth noting the relative positive interest across all groups regardless of gender, as well as the relative similarity in interest between genders for several of the teachers (e.g., P, Q, R, X, Z, AA).

4.3 Students' written responses

Included in the post-unit student motivation surveys were open-ended prompts requiring students to submit a written response. To further analyze students' experiences with the game and simulation design units, we coded student responses to an open response prompt that asked students: *H c a ab a c ?*

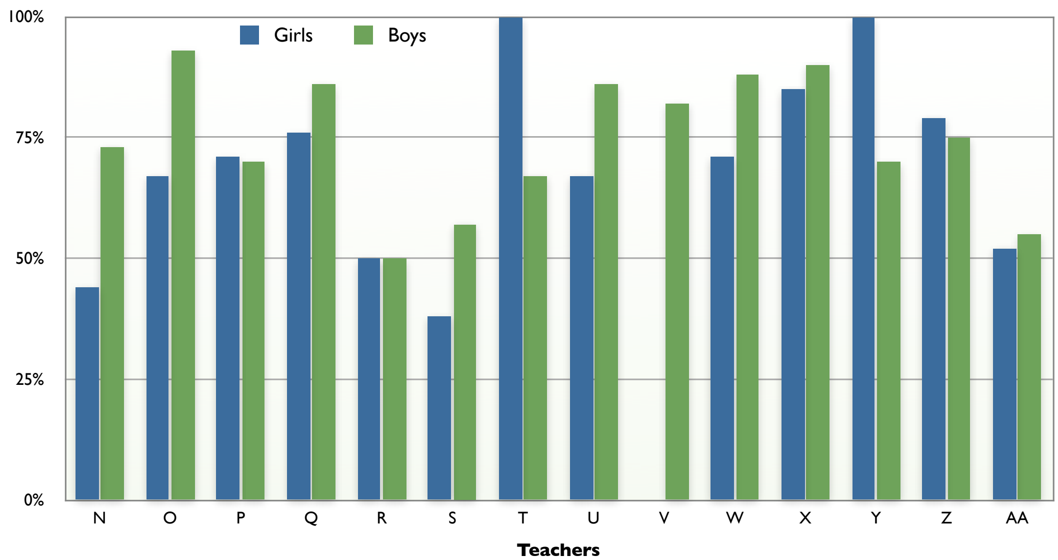

Figure 2: Student interest in taking another game design class for each teacher in Year 2, disaggregated by gender.

From a sample of 425 responses to this prompt, we coded responses as positive, neutral, or negative. For this sample, 65% (n_{Male}=152, n_{Female}=124) were coded as a positive response, 21% (n_{Male}=37, n_{Female}=54) were neutral, 7% (n_{Male}=17, n_{Female}=14) were interpreted as negative, and 6% (n_{Male}=7, n_{Female}=20) of the responses were blank. A sample of responses for each of these categories is included below.

4.3.1 P a

Positive attributions of students' self-reported experience included new insights, recognition of computer processes, descriptions of how computers could be used to support design, and increased self-confidence. The brief list included below is representative of the types of responses coded as positive.

- *Now I know what computer programmers do. I never knew you could do this stuff.*
- *I never thought that computers could be not for super smart people but now i know you don't have to be super smart!*
- *It made me think if this then this*
- *Agent Sheets makes me want to make more complex games and take more computer classes.*
- *It made me think that I don't have to use other people's games on the computer i can just create my own.*
- *Agent Sheets opened up a new process in using the computer, using cause and effect to make an action.*
- *It made me feel less hopeless with computers*

With respect to students' interest in future engagement in similar activities, we assert that self-reported new learning and a sense of increased internal locus of control [13] can serve as powerful and enduring motivators supporting future pursuit of computer-based design.

4.3.2 N a a

For a statement to be coded as neutral, the response needed to include an expression of prior similar experience or no change in the ways computers work.

- *It didn't really make me think differently about ways to use the computer. I already know a lot about website design.*

- *I don't think it made me think differently about computers because it was just a computer program that teaches us how to create games… that was pretty much all that it did*.

4.3.3 N a a

Negative attribution of the experience suggested that the student may be less inclined to pursue future computer courses or career pathways. Although we don’t necessarily see individual recognition of challenge or identity development as negative, per se, it is negative with respect to the CS pipeline.

- *I use to think computers were so easy, but not no more [sic]*.
- *That I should not make computer games for living*.

When students were asked how the experience changed their understanding of computers, the percentage of positive attributions for a sample of participating students was approximately the same percentage of students who were interested in taking another game design class (i.e., 65%).

5. Discussion

When comparing students’ interests in taking another game design class to gender ratio enrollments in courses, an intriguing pattern emerged. When girl-to-boy enrollment ratios for a teacher approached 40:60, there appeared to be a notable gender difference, favoring boys, with respect to students interested in taking another game design class. This gender difference may be exacerbated when the observed instruction is teacher directed and highly prescriptive. In some cases, these gender differences in student interest were reduced or completely eliminated for teachers who utilized a guided discovery approach. Given the limited number of teachers and classrooms that have been used as the basis for this conjecture, further research at greater scale is warranted that can examine the effects of pedagogy on gender differences towards computer science education.

In general, two thirds of participating students had positive responses to both the “course taking” prompt and the “understanding computers” prompt. To ensure broader participation with respect to girls, pedagogy may have a stronger impact on student attitudes. Such findings have implications for giving greater attention to pre-service education opportunities in computer science and professional development opportunities to support student ownership, creativity and access to the zone of proximal flow.

6. ACKNOWLEDGMENTS

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