CHILDREN AS EDUCATIONAL COMPUTER GAME DESIGNERS: AN EXPLORATORY STUDY

Ahmet Baytak
Computer Science Department
Harran University, Turkey
abaytak@harran.edu.tr

Susan M. Land
Learning and Performance Technology Department
The Pennsylvania State University, US
sland@psu.edu

Brian K. Smith
Rhode Island School of Design, US
bsmith@risd.edu

ABSTRACT
This study investigated how children designed computer games as artifacts that reflected their understanding of nutrition. Ten 5th grade students were asked to design computer games with the software *Game Maker* for the purpose of teaching 1st graders about nutrition. The results from the case study show that students were able to express their personal thoughts and intentions by designing and developing realistic computer games in a complex programming environment. Our findings point to gender implications and other contextual factors that motivated social interaction around game design and programming strategies.

INTRODUCTION
In the early 1990's, Seymour Papert forwarded the notion of "constructionism" to suggests that learning is most meaningful when learners are actively engaged in building artifacts (Papert, 1991). Constructionism is based theoretically on Piaget's ideas of students as builders of their own knowledge. Piaget's statement "that children don't get ideas; they make them" guides the direction of constructionism (Han & Bhattacharya, 2001). Constructionism is also tightly connected with Papert's early work with Logo and its subsequent form of Lego-Logo toys.

Papert characterized constructionism as encompassing two interconnected processes: The first is an internal and an active process where students construct knowledge from their experiences of the world. The second process is external, reflecting the belief that students learn best by making artifacts that can be shared with others (Grant, 2002; Kafai & Resnick, 1996; Papert, 1991). In other words, constructionism takes knowledge from an abstract mode to a concrete mode. Student artifacts can be anything from a poem or a webpage, to more complex artifacts like an origami, or a computer game.

Papert's LOGO project with elementary school students to learn math is perhaps one of the best known for illustrating learning-by-constructing. However, prior studies have been conducted in the domains of math (Harel, 1991; Kafai, 1998), science (Hmelo et al., 2000; Kafai, 2005; Brandes, 1996; Kolodner, et al., 2003), music (Gargarian, 1996), and Thai language and emotional development (Tangdhanakanond, Pitiyanuwat, & Archwamety, 2006).

Artifact development in constructionist environments can be facilitated in various ways. Recent work in "learning by designing" emphasizes constructing artifacts by programming computers or designing games (Kafai, 2005). Designing sharable artifacts that reflect students' different styles of thinking and learning is key. Kafai claimed that designing artifacts by programming software helps students reformulate their understanding and express their personal ideas and feelings about not only the subject but also the artifact. Papert also sees programming or game making as a construction tool for personal expression and knowledge construction, and this helps students explore psychological and cultural aspects of learning (Papert, 1995).

BACKGROUND ON GAME DESIGN FOR CONSTRUCTIONIST LEARNING
In recent years, considerable interest has been generated in the educational potential of computer games (Dickey, 2005). With the commercial success of virtual gaming worlds for children, such as *Webkins* or *NeoPets*, computer games have become an important part of everyday life for children. Whereas most research concentrates on the design and effects of gaming, our research builds off the work of Papert and others (Harel,

1991; Kafai, 1998; 2006; Overmars, 2004) to investigate the educational impact of children designing their own computer games. That is, children were supported to become "producers" rather than "consumers" of computer games (Kafai, 2006). Overmars' research led to the development of software (*Game Maker*) that supported game design by students with no knowledge of programming code. The educational advantages of students creating computer games for other students was recently discussed by Lim (2008) and Prensky (2008) as a way to integrate gaming into the sociocultural fabric of schools. Prensky identified three main strategies for incorporating student game design into classrooms: (a) students create games for material they are currently studying; (b) students create games for other, younger students; and (c) students create games for design-only competitions. Our work incorporates the first two strategies.

Constructionism also emphasizes the social nature of learning. Artifacts are developed, in part, so they can be publicly shared and discussed. Thus, collaborative settings are commonplace. Shaw (1996) noted that students in social settings engage in a cycle of development leading to external and shared social constructs. Constructionism mobilizes the knowledge of the community to support learning among its members (Gargarian, 1996). Hence, artifact development should entail exposure to activities that promote collaboration and sharing. For example, Kolodner and her colleagues (2003) used a "class pin-up session" to support students to collaboratively predict how their designed artifacts would behave, and whole-class discussion around a whiteboard to review what students learned form previous steps. They used small group and community rituals to explain, justify, and prepare reports about what they were learning, and poster sessions to present final products with the entire study group.

Although computer gaming may be perceived as a solitary activity, the act of creating games would involve a responsive social community. Even among single game players, peers watch each other, and compare and share strategies and tips (Lim, 2008). In the context of game design, many opportunities can be created for sharing strategies and designs based on a need to know. Kafai (2005) used group discussion during her game design project to help the students share their game designs, ideas, and difficulties with applying the subject to games. Similarly, Brandes (1996) implemented ethnographic observations and small group projects into her study where students had the chance to try each others' designs and leave feedback or incorporate some ideas for their own designs.

THE PURPOSE OF THE STUDY

The purpose of this study was to explore how children designed computer games as artifacts that reflected their understanding of nutrition. We wanted to examine the process used by elementary school students to construct understanding of nutrition knowledge by designing the games. In order to accomplish this goal, we focused on the following research questions:

1-What conceptions of nutrition knowledge were used or evident in the game design?
2-What programming strategies did students use to develop their game over time?
3-What was the role of social interaction on students' game design?

THE MOTHODS

Participants and Context

Ten 5th graders, 4 girls and 6 boys, participated in this study as part of their science class during a unit on nutrition. All students' names presented are pseudonyms. Prior to the game design task, students were taught basic nutrition concepts such as food groups and serving sizes, over a period of four classes. The main task assigned to students for our study was to design a computer game using a program called *Game Maker* to teach first graders about nutrition. Two students in the class had prior experience using the *Game Maker* software, but none of the remaining eight students had used the software before. At the end of the project, the first graders from the same school played the games designed by 5th-graders. Students spent approximately 8 weeks developing their games.

GameMaker: The Design Software

All students used *Game Maker* to design their computer games. *Game Maker* (Overmars, 2004) was designed to support the rapid development of computer games and learning of computer science principles. The software is available to download free of charge (http://www.yoyogames.com/make), which was an important consideration for use in our project in a public school. A simple graphical interface allows users to create characters, settings, and behaviors without writing traditional code. The software comes with a collection of freeware images, sounds, and sample games to help novice designers with their design and development. Indeed, one of the most powerful attributes of *Game Maker* is its library of existing games. These can be modified, or *modded*, to create new games.

Modding offers a number of advantages over designing games from scratch (Emmerson, 2004; Seif El-Nasr & Smith, 2006), and this feature was central in our decision to use *Game Maker* for the current study. Because modding begins with popular, proven game concepts, the resulting variations are more likely to have elements of challenge, curiosity, fantasy, and other properties associated with engaging games. For instance, one student in our study began her project with a Pac-Man game since she and others in her class enjoyed playing it. She was able to modify one of *Game Maker*'s Pac-Man games, changing the icons to food images and developing new scoring models that rewarded the Pac-Man for eating healthy (see Figure 1). *Game Maker*'s facilities to grab and modify existing games allowed her to develop a working prototype that addressed nutrition ideas in one week by eliminating many of the burdens associated with implementing computer games.

For instance, much of the technical knowledge related to computer programming can be overcome with *GameMaker*'s graphical approach to creating characters, levels, events, and other game objects. Designers can choose actions from libraries, drag and drop these onto existing or created game objects, and essentially transform games into similar yet different versions of themselves. With *Game Maker*' students start with making sprites either using the given images or making their own images with its image editor. The students then turn these sprites into objects and add actions to them (Figure 1). Then students design rooms (levels) and add objects to make platforms ready for playing. Depending on their game style, some students used only one room, but others students used more than one room. Figure 1 shows a sample screen shot of a student's game as it was being developed.

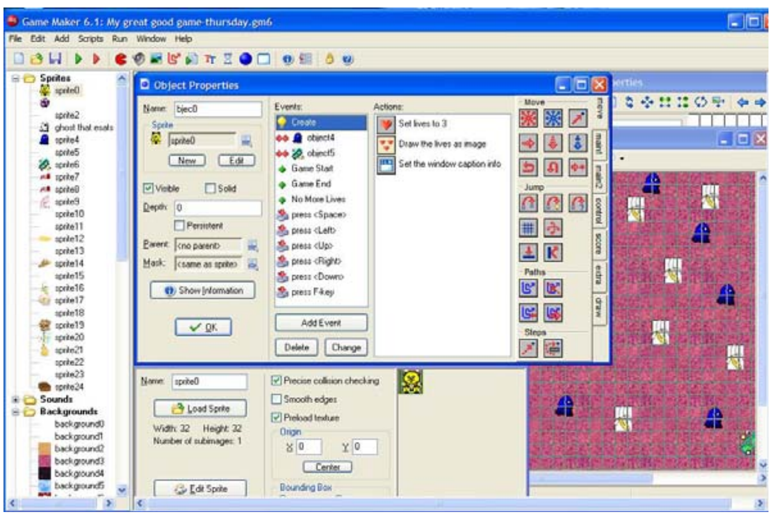

Figure 1. A screenshot from a girl student's *Game Maker* platform: Adding actions to the character

Procedures

The students met for 45 minute sessions twice a week for 8 weeks. Students were first taught how to use the *Game Maker* software. Similar to Hmelo and her colleagues' (2000), students were presented with some design examples and challenges in *Game Maker*. In order for students to understand the software, they were asked to modify some part of the template games that came with *Game Maker*. Two teachers, the technology teacher and science teacher, facilitated the students in their designs. The technology teacher, who is also the lead author, checked the students' games and left feedback during the class sessions. Feedback mainly consisted of questions to students to prompt new ideas in the designs. He also supported the students if they had any questions on programming. The science teacher played students' games and gave them guidance on implementing nutrition facts correctly. However, the students were not required to change their games based on teachers' feedback.

The study was designed to promote collaboration among students. Similar to previous studies (Kolodner et al., 2003; Harel, 1991; Hmelo et al., 2000), students were encouraged to look at peers' games to not only give feedback but also to get ideas for their own designs. Since it was a small class, the students would typically ask the entire class for guidance on how to perform certain programming tasks. That collaboration was informal, in that students could ask for help at any time during the sessions.

After the students designed their games, 16 first graders came into the class and tried out the games. The first graders played the games in pairs, with the game designer of each game (5^{th} graders) sitting next to them. The first graders provided the game designers with their opinions as they played each game. Each student's game was tested by approximately 6 different pairs of 1st graders. Once the project ended, all ten 5th graders were interviewed individually for one hour. The interview began with a series of guided questions regarding students' goals, strategies, and perceptions for the game design process. Emphasis was placed on what students believed they learned about nutrition, how they learned the programming strategies, and why they made specific game design decisions.

Data Sources and Design

The research used a case study as the research methodology (Yin, 2002). This methodology is appropriate for investigating complex, contemporary phenomena within its authentic context. The unit of analysis for our case study was the entire classroom learning environment, including all students, teachers, and artifacts. Case results were compared against, and explained according to, previous theoretical models developed by Kafai (1998) and Kafai, (2006).

A primary data source for this study was the participants' computer games. Of the 10 games designed by the students, eight games were analyzed, as two of them were not accessible due to technical problems. The students' games were saved separately by weeks, so multiple iterations of the games at various stages of development were examined. Most of the students started with a draft game in the first week and then decided on one design idea that was developed throughout the activity.

The following data sources were collected and used in the interpretation of results: (a) students' written goals for their game design: (b) interviews with the participants following the game design; (c) the participants' games; and (d) classroom observations. The lead author was present for all sessions. All interviews with participants were transcribed and later analyzed for insights into each research question. Initially, data were examined according to each participant, using matrices that represented each student's activities and verbalizations that were relevant for each research question. Stored iterations of the games were examined and coded for changes across time. Then, data were examined broadly for different examples of game design activity; similar instances were grouped according to major categories. This approach allowed us to identify trends within and across participants for a given question (Miles & Huberman, 1994). Two researchers (the first and third authors) collaborated on the analyses, allowing for discussion and agreement on how the data was to be interpreted.

RESULTS

An overall description of the characteristics of the students' games is first presented, along with the results according to each research question (nutrition concepts, programming strategies, social interaction).

DESCRIPTION OF THE STUDENTS' GAMES

Students' games were analyzed in order to generate an overall description of the artifacts they created. The games were analyzed according to three characteristics identified by Kafai (1998): (a) game genre (b) game world and game characters (c) interaction and feedback.

3.1.1. Game genre. The genre all of the students' games can be categorized as arcade. All of the games were comprised of several levels where each level was progressively harder for the players. Similar to other commercial games, such as *Pac-Man*, the players' goal in all of the games was to keep the main characters alive to finish the game. The game would end if the game character lost life or a certain number of points.

The games all involved a series of actions needed for a main character to stay alive. We observed some differences in the methods used to save characters, some of which may point to gender differences. One should note, however, that the small sample size of students in this study limited such interpretations. Nonetheless, we observed that all the boys' games involved destroying enemies or unhealthy foods to make the main character survive. For example, Tom's character shoots the brownies. Markus' stays away from enemies and makes them crash. Sammy's character also destroys all the "bad foods" by touching the magic food. On the other hand, none of the girls' games involved destroying characters. In order to survive, the players of the girls' games had to simply stay away from the "unhealthy food" and get the "healthy food".

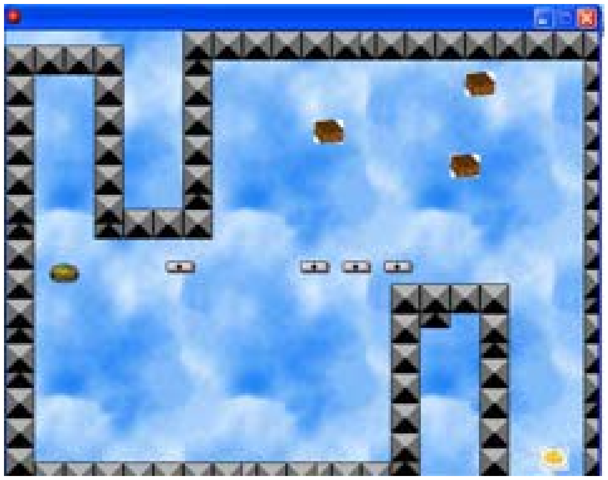

Figure 2. Another example from students' game designs; Tom's actual game that he tyied shoot 'unhealthy food' on his way.

Game world and game characters. The students' game worlds, or as Robertson (2004) describes as "game settings", had several commonalities. Interestingly, in this study none of the students used a real world environment as the setting for their games. Most the games took place in an imaginary setting with boundaries around which the character bounced. Otherwise, almost all the environments allowed the players to move in four directions (left, right, up, and down). The one exception was Markus' game, and his game was a food driving game that was modified from a car driving template game. The environment in his game was similar to a highway where food icons tried to escape from the "bad food" and drive carefully.

All the students chose a main character that represented the player whose goal was to eat "healthy foods" and stay away from "unhealthy foods". None of students designed a main character with a specified gender. Table 1 summarizes characteristics of the students' game characters.

Table 1: Students game settings and characters

Student	Main Character	Supporting Characters	Design/ Gallery	Characte r Gender	Known character
Carol	a stick man	8 characters and 1 of them moves	Her own design	No gender specified	Not for the games that she had played
Flora	Initial of her name in a circle	20 characters and 2 of them move	Her own design	No gender specified	Not for the games that she had played
Erin	Teddy bear	31 characters and 1 of them moves	From the image gallery	No gender specified	Not for the games that she had played
Amanda	Pac-man	Added 7 new characters to the original game; 2 of them move	From the image gallery	No gender specified	Common character
Tom	Hamburger	12 characters and 5 of them move	From the image gallery	No gender specified	Not for the games that he had played
Sammy	a Pokémon character	13 characters and 3 of them move	From the image gallery	No gender specified	Common character
Markus	Pac-man	Added 3 new characters to the original game; 4 of them move	From the image gallery	No gender specified	Common character
John	A bird	14 characters and 2 of them move	From the image gallery	No gender specified	Common character

Game interaction and feedback. In most games, the feedback for the players was based on action rather than text feedback. When players lost the game, most of the students required the players to either restart the game from the beginning or end the game by showing the score. Except for two girls, Flora and Erin, no students gave any directions for the players to explain the steps in the game. However, these two girls informed the player of the goal and provided a brief message when the games ended. For example, Erin's game started with the following message: "*Avoid the blue ghosts and collect all of the balls*". When the game ended, the message stated; "*Sorry you lost. Come back and try again later!*" Similarly, Flora added a character that resembled Einstein to guide the player throughout the game. In her game, when the main character touched that character, the following message popped-up; "*Hi my name is Bob... When you're done, come to me!*" Flora's games ended with the standard "*Game Over!*" message.

How was nutrition knowledge used or evident in students' game designs?
For this question, we examined what conceptions of nutrition knowledge were evident in the students' games. Based on analyses of children's games and interview data, most students represented the nutrition concept of "eat healthy foods and avoid unhealthy foods' in their game design. For instance, typically healthy foods (e.g. vegetables and fruits) were used as a good/positive character such as fuel, point-gaining agent, or key to the next level; while unhealthy foods (e.g. hamburger and desserts) were used as a negative character such as speed reducer, point/energy-losing agent, or game-over agent.

Although many children simply used healthy foods as good agents vs. unhealthy foods as bad agents in their games like conventional game characters, the interviews revealed that a few children connected it to the concept of healthiness of our body. For instance, Tom's main character moved faster when it ate or touched salads. Tom explained that salads were selected because they would give nutrients that our body needed. Therefore, eating salads would make our body stronger 'like protein' and that's why his main game character could move faster.

In addition, some of the children tried to apply 'portion size' (eating adequate amount of each food group) to their game in various ways. For example, Flora tried to deliver the portion size concept indirectly by limiting the number of blueberries used on her game because she knew eating too much fruit is not optimal; Markus used the portion size concept more directly in his game: "…if you ate the strawberries too much or if you ate the green beans too often it would actually give you a "power down," you would lose the propane that you had…"

However, children's applications of the portion size concept to their final version of the game appeared limited and superficial rather than complete and showing deeper understanding of the concept. This could mainly be due to time limitations or technical skills. For example, Flora adjusted the number of blueberries based on the portion size recommendation but didn't apply correct portion size to the all the food items used on her game. The interview revealed that Flora was fully aware of it and wanted to apply the right portion size for all food items on the next version of the game if she had more time for the project. Likewise, Markus described the technical difficulties he experienced to apply serving size to his game:

> Researcher (R) : …Do you have an example of not eating too much?
> Markus (M) : Well that's one of the features I couldn't find out…I was going to put on a limit and it would go down slowly and if you ate the green beans every time it came down or every time the strawberries appeared, you would fall back of course
> R: So like when you were trying to put the serving size in this game too?
> M: Yes
> R: OK, so you were aware of the serving size? How many veggies?
> M: I couldn't find out how to put the limit on…

Overall, it was observed that most of the children applied a basic nutrition concept of "fruits and vegetables are healthy but too many desserts is unhealthy" in their game design. A few children tried to apply the concept of portion size to their game but it was not easy for them to implement with limited time and technical skills.

What programming strategies did students use to develop their game over time?
To address this question, we examined the students' planning process and strategies that they used to program or design their educational games. Although more than half of the students reported playing video games often, only two students had explored *Game Maker* or similar game design programs before the project. However, by the end of the project, all the students were able to build functional games even in a complex object-oriented programming environment. Two primary strategies were used to design the games overall. One was to start from the existing "template" games available in the software and then to add on to them to make their own games. The second strategy involved designing a custom game from beginning to end, with students building their own

overall structure, objects, characters, and rooms. Among the 8 games examined, two students used the templates to build their games and the remaining 6 designed their own games without using templates. The latter strategy is considerably more complex.

Overall, all students kept with their game theme over time. That is, once students started work on their games, they did not alter the overall theme and design. Even though students made changes to the games by adding new features throughout the project, the overall concept and theme of the games remained. This finding differed from prior research conducted by Kafai (1998) that showed that students made changes in overall game theme and concept.

Nevertheless, the students' games reflected substantial progress in terms of students' design skills over a short time. For example, Flora indicated that she played games often but had never before used game design software. Yet, by the end of the project, she was able to design an educational game that reflected nutrition concepts. The characters in her game not only performed basic moves but also functioned to make the player lose points when the main character touched "unhealthy food". She also added interactive feedback, a more advanced function that few students included, to guide the player of her game.

Analyses of interviews, artifacts, and observations showed that the students used various strategies to design their games. One of the strategies that all the students used was exploring the coding examples in the template games. Since the students could access the coding part of the template games, they were able to see how each coding feature made the game different. The students used that resource wisely. However, that strategy may have also led the students to pursue game themes and ideas that were driven by those available as templates. Overall, students interacted with their games by designing, debugging and redesigning. This trial and error process helped the students to correct some programming errors in their games. The students tested their games after adding each function, learning what worked and did not work, thus refining their skills.

Role of social interaction

Social interaction was supported in the classroom through informal teacher and peer interactions during the design process, as well as at the end of the project through structured feedback when first graders were invited to the class to try out the games. The class was structured loosely in a setting that encouraged students to move around and share knowledge and strategies informally. It was common in the classroom for a student to vocalize his or her excitement over getting a strategy to work, and then to have several students stop their work to come over and see the new development. Also common were informal requests to have peers test out part of a students' game, or for others to ask around to the class for help in accomplishing a specific programming goal. One student in particular was experienced in designing games using *GameMaker* (Alan), and he became the peer "expert" of the class who was frequently sought out for help. These highly informal ways of interaction were central in influencing the development of students' games over time. Through the simple act of observing what others incorporated into their games, ideas and techniques would spread throughout the class.

The teachers acted as facilitators in the design process. Instead of teaching every step of how to design a game, the teacher showed the students how to access necessary information. The technology teacher was a useful resource when students were seeking technical help. Moreover, the teacher promoted peer collaboration by referring students' questions to other students who might have good answers for a specific problem. As mentioned previously, this type of peer collaboration was the dominant strategy used to design and build upon games. Similar to what Kafai and Harel call as learning through consulting (Kafai & Harel, 1991), in this study, learning from peers helped students not only learn basic coding from each other but also to collaborate on game designs throughout the project. For example, Alan was the only student at the start of the project who knew how to write code in *Game Maker*. However, with Alan's help, most of the students added some coding or scripting to their game designs. Collaboration in game design seemed to influence students to add new features to their games.

Collaboration among the students was not limited to the game design process. The students also asked questions to each other regarding nutrition. For instance, we observed some students asking others if they had proper portion sizes of certain foods in their games. Another way of student collaboration during the design project was students' testing each others' games. For example, one student (Erin) said: "*During class, they were like, 'Erin'! 'You wanna come and see? Do you like this?' and things like that…*" Testing each others' games helped students provide peer feedback and to build new features into their games, as a result of being exposed to new ideas. In addition, testing games was useful to see the errors in coding, giving them the chance to make necessary changes to their games.

The interaction between fifth graders and first graders added value to our study. Since the designers were asked to design their games for a target audience, students tried to design for that grade level by considering usability, accessibility, and other game design components. After observing the first graders' testing process of their software at the end of the project, fifth graders had a chance to interact with them. Most of the first graders commented that they like the games, and noted that they should not eat unhealthy food. They were also asked if they were able to move the main character and get points in the game they played. Even though some students thought the games they played were hard, they were able to move the main character and pass at least the first level of the game. The first graders reported being excited about the games, and wanted to play more of them. Based on our interviews, the fifth graders concurred that the feedback they received from the first graders was productive for considering how to improve their game design and content.

CONCLUSIONS

This study investigated how children designed computer games as artifacts that reflected their understanding of nutrition. Our study showed that the students were able to successfully express their personal thoughts and intentions by designing and developing computer games in an accessible programming environment. Although the focus of our analyses was on the children who designed the games, the first graders who played them also reportedly enjoyed the games. They expressed awareness of which foods were healthy and unhealthy in the game, and indicated that they wanted to play the games again during the try-out period.

One noteworthy aspect of this study relates to the girls' engagement in designing computer games. The girls in our project designed computer games, as opposed to just playing games. Also important is the fact that some of the girls continued to design computer games in after-school activities after the project ended. Erin, for instance, continued designing computer games six months after the project ended, even though she stated that she didn't play computer games before the project. In the end, the girls' games were as educational as boys' games. Our study findings are consistent with the idea that boys are likely to see computers as a playful recreational toy, whereas girls see them as a tool to accomplish a task (Miller, Chaika, & Groppe 1996).

Nevertheless, the project also dealt with some challenges. Since it was largely the students' first time designing computer games with *Game Maker*, the students had technical difficulties to implement the ideas they planned. Some students, for instance, had to draw their own food icons since the icons they wanted to use in their games either were not provided or were oversized for their games. Like other studies of students developing artifacts, the process of making the artifacts themselves sometimes becomes the overwhelming focus, rather than the knowledge goals of the activity (Barron et al., 1998).

Our study was also limited due to the size of the sample (n=10). Our study pointed to some possible gender-influenced differences in how games are designed that could be explored in future research. Future studies could also focus on addressing issues of concept learning and measurement – particularly in regard to assessing the knowledge gains associated with such an activity. To gain traction in school settings, strong evidence of concept learning and programming skills need to be established. Notwithstanding, our findings provide some insights into the process used by students to design computer games that reflect nutrition concepts. Our preliminary data support the notion that learning by designing computer games promotes engagement during learning, regardless of gender, and also can lead to productive social interaction.

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