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NOT ALL MAP USE IS CREATED EQUAL:

INFLUENCE OF MAPPING TASKS ON CHILDREN'S PERFORMANCE,

STRATEGY USE, AND AQUISITION OF SURVEY KNOWLEDGE

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ABSTRACT

The ability to think and act spatially has a variety of implications for human functioning and survival. Maps are an important tool for both navigating through and learning about the environment. Better understanding of how maps influence our spatial thought will help us to develop more complete theories of spatial development and provide better spatial education. The present study investigated the following aspects of children's map-use: (a) whether or not two different mapping tasks elicit similar performance and strategies from children, (b) if using a map results in better survey knowledge compared to not using a map, and (c) how individual differences in spatial ability relate to map-use performance.

To address these issues, 9- to 10-year-old children (N = 58) were tested in one of three conditions: comprehension, production, or no-map. In the comprehension condition, children used a map marked with target locations and tried to place flags in the environment precisely at those target locations. In the production condition, children searched for flags in the environment and then placed stickers on a map to indicate the flags' locations. In the no-map condition, children searched for flags without a map in order to solve a riddle. After completing the search task in one of these three conditions, children completed measures of environmental survey knowledge and of spatial skills.

Comprehension and production tasks were hypothesized to be conducive to different levels of strategy use during the task. Performance was expected to be affected by these different strategies. Specifically, it was predicted that the comprehension task would elicit greater map use (looking at, aligning, and touching the map), which would, in turn, lead to better performance. It was also predicted that children in either map condition (comprehension or production) would do better on measures of survey knowledge in comparison to children in the no-map condition. Spatial skills as measured by paper-and-pencil tests were hypothesized to be positively related to performance on the mapping task.

As hypothesized, results showed that accuracy in placing the flags or stickers differed between children in the comprehension and production groups. This effect was mediated by strategy use such that those in the comprehension condition spent a greater proportion of time aligning, looking at, and touching the map and this greater use of strategies was associated with better performance on placing the flags. The hypothesis that map use would lead to better survey knowledge was not supported by the data and potential reasons for this finding are discussed. Results provided support for the hypothesis that performance on laboratory paper-and-pencil spatial tasks would predict performance on the mapping tasks.

This study shows that comprehension and production mapping tasks do not elicit equivalent strategies or performance, and thus implies that caution is needed when selecting methods for mapping research. The finding that performing a search task in an environment with a map does

not necessarily lead to better survey knowledge than exploring it without a map raises several questions about how map use might be related to the acquisition of survey knowledge more generally. More broadly, this study has implications for the design of mobile mapping devices and the education of map skills.

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Chapter 1

Introduction

Our lives, though we may not consciously recognize it, are greatly influenced by our ability to perceive, remember, and cognitively manipulate the spatial relationships we experience in the world. The survival of our human ancestors depended upon their ability to remember locations with rich food supplies and safe shelter from predators and the elements. Today it may be less obvious, but these abilities still increase our chance for survival as we learn what neighborhoods to avoid late at night in a city, vacation destinations susceptible to hurricanes, hazardous routes in a blizzard, and how to successfully navigate our everyday world while avoiding accidents of various kinds. Less directly related to our survival, these skills influence the kind of career we pursue, the things we do in our spare time, the places we decide to live, and our ability to accomplish the minutia of daily life such as arranging furniture, or packing a car.

How is our knowledge of the spatial world formed? What experiences shape how we think about spatial relationships? Questions in this vein have long interested cognitive and developmental psychologists, as well as geographers and philosophers. The answers to these questions have both epistemological and pedagogical implications. The better we understand how our knowledge of the world is formed, the better prepared we are to support spatial learning, an important yet often overlooked cognitive domain (Liben, 2006).

One influence on our spatial thought may be the representations we use to convey spatial relationships. Jerome Bruner has long extolled the importance of symbolic thought and the role of physical representations in the process of symbolic thought. He has suggested that the use of symbolic representations emerges from enactive and iconic representation and each of these influence thought (Bruner, Oliver, & Greenfield, 1966). Bruner mainly addresses language in his writings, but symbolic representations include any arbitrary symbolic system, including physical representations such as maps. In essence, Bruner claims that how we perceive reality is shaped by the symbolic systems we use to represent it, stating that reality is mediated through "cultural products, like language and other symbolic systems" (Bruner, 1991, p. 3). I would surely not be the first to claim that maps are a key symbolic system that influences our ability to think and reason about space (Uttal, Fisher, & Taylor, 2006). Some have even argued that maps are a culturally universal symbolic medium with which we try to organize spatial information (Stea, Blaut, & Stephens, 1996).

Maps are integral to the way we think spatially because they alter the way we view our world and influence our knowledge about the world. Wood and Fels (1992) have discussed the varied ways in which maps may alter our spatial thought by making present that which cannot be seen, and point out that the map is so useful we naturally try to construct mental maps of spaces. However, maps are not a replication of the real world and can lead to distorted representations of the real space. For example, with a Mercator projection of the Earth, the area of Greenland is distorted such that it appears it has a greater area than that of Africa. This is because a Mercator projection distorts area in order to preserve direction. Both cannot be preserved in a 2-dimensional representation of the Earth (Liben, 2001). Thus when studying a Mercator map, one could make the incorrect conclusion that Africa is smaller than Greenland.

Despite potential distortions, maps help to facilitate conclusions and observations that are not possible with the limited means by which we are able to directly experience our world (Liben, 2001). As Wood and Fels put it: "And this, essentially is what maps give us, *reality*, a reality that exceeds our vision, our reach, the span of our days, a reality we achieve no other way" (pp. 4). Winchester (2001) describes the dramatic influence that William Smith's development of geological maps and stratigraphy had on our knowledge about the world. From

Smith's observations and maps it became apparent that the continents were not always separate land masses and as a result geologists were able to provide evidence for an ancient super-continent. This is an example of how maps allow us to think beyond what is directly observable in order to achieve a greater understanding. Sholl (1999) has also found that using a map alters the frame of reference we use when making judgments about locations. When using a map, we are more likely to switch to an allocentric (or externally centered) frame of reference as opposed to an egocentric (or self-centered) frame. This has practical and physical implications, but it also intimates the way in which the use of maps changes the foundation of our perception. Maps literally frame the way we perceive reality, just as Wood and Fels claimed.

Not only do the representations we use influence our perspective, but the ways in which we use them may also have an impact. Goodman and Elgin (1988) argue that what we perceive as fact is shaped by the lens we apply to the world, in turn, that lens is shaped by our experiences and our active construction of regularities and reality. This lens may change as we experience new things and incorporate novel experiences into our existing schemas. Therefore, knowledge is necessarily dependent on experience, but simultaneously experience is dependent on knowledge. In Goodman and Elgin's words: "Beliefs and expectations supply systems of categories or kinds that structure what we perceive" (pp. 5). This is consistent with the Piagetian constructivist concepts of assimilation and accommodation. From a Piagetian perspective, as we encounter new information we must incorporate it into our existing thoughts and beliefs about the world. If that is not possible then we must adapt our thoughts and beliefs to be able to accommodate the new information. Piaget also argued that the ways in which we engage with the world shape our construction of reality (Piaget, 1970). As stated earlier, and as is supported by Piaget's constructivist approach, it is not only our interaction with maps or with other symbolic systems that allows us to engage with our world, but it is the methods we use to do so which help to shape our experiences and our thoughts about reality (e.g., Uttal et al., 2006).

In this paper, I aim to delve into one aspect of how maps and the ways in which they are used shape our spatial understanding. Specifically, I investigate the influence of map use on the acquisition of a survey perspective of an explored space. As is reviewed below, maps have been shown in a variety of studies to aid in the acquisition of survey knowledge. However, this literature has not adequately established that children have the capacity to do this in a naturalistic setting when using a map for common goal-directed purposes. In addition, there is no literature demonstrating that the various methods for studying map use are equivalent for understanding map-use abilities. The current research was designed to examine these issues. Children aged 9-10 years old were asked to perform one of two mapping tasks in a large-scale space. The tasks mimic everyday uses of maps such as finding one's location on a map or navigating to a point indicated on the map. To do this, children were asked to place flags in the environment based on locations indicated on a map in the comprehension condition and to place stickers on a map based on flags found in the environment in the production condition. A pointing task and a shortest route-to-target task were then used to measure survey knowledge acquisition. Of interest was whether performance on placing the flags and stickers was similar or different between comprehension and production conditions, whether observable behaviors the children engaged in while completing the task were similar or different, and whether children implicitly gain a better survey perspective from performing these tasks (when compared to exploring the space without a map, hereafter referred to as the no-map condition). Because basic spatial skills are likely important for these tasks, as discussed in more detail below, a battery of basic spatial skill measures was included in examining the relationships between task, process, target placement performance, and survey knowledge.

Literature Review

Below I outline the literature regarding development of cognitive maps or survey perspectives, development of the ability to use physical maps and the methods used to study map use, a brief review regarding implicit learning in relation to the spatial domain, and a discussion of the ability to predict large-scale environmental learning with small-scale paper-and-pencil laboratory tasks. Before turning to this review I first make a brief argument as to why the study of paper map use is still relevant in an era when automated personal global positioning systems (GPSs) and other digital devices make it possible to navigate without having to read a map.

Defending paper maps. Some readers may argue that the increased use of personal GPS devices is making the ability to use a paper map obsolete. My rebuttal to this argument is two-fold. First, electronically automated systems can and do fail. Failure can occur when batteries run out or when a satellite signal cannot be received. Failure can also occur when a GPS has errors, and thus gives inaccurate directions. Incorrect GPS directions have been blamed for numerous New York City accidents (USLaw.com), a man nearly driving off a cliff (Saranow, 2008), and a couple taking an unmaintained road as a “shortcut”, stranding them in the snow for three days (Hagan, Netter, Clarke, & Ehrlich, 2009). These incidents, among others, could be avoided if the navigators were not relying solely on their GPS.

Secondly, the increased use of GPS may lead to a deficiency in spatial ability and spatial knowledge. The literature is still somewhat limited in this vein, but several studies have shown a significant decrease in spatial knowledge when automated directions are given compared to using a map to navigate (Burnett & Lee, 2005; Fenech, Drews, & Bakdash, 2010; Parush, Ahuvia, & Erev, 2007; Wu, Zhang & Zhang, 2009), and others have shown that route knowledge is acquired more effectively than survey knowledge when using personal navigation devices (Krüger, Aslan, & Zimmer, 2004). Even handheld devices that are able to display electronic maps may inhibit spatial learning because the screen size may limit the ability to integrate spatial information in the way a paper map allows (Gartner & Hiller, 2009). This suggests that it may be important to be able to establish your location in relation to the broader surroundings in order to gain environmental knowledge through map use.

Of course GPSs can have many benefits when used appropriately. As one example, some devices use traffic information to suggest routes, which can help drivers avoid unnecessary delays. However, as evidenced by the example given earlier of the stranded couple, it would be best for users to either be sure of the route they are taking or to have the ability to read a map to confirm the alternate route. Additionally, there are efforts underway to make automated directions more interactive and to couple them with spatially relevant information in order to reduce deleterious effects on spatial knowledge (e.g. Hirtle & Srinivas, 2010; Li, 2010). These efforts are promising, though it is not yet clear how effective the various strategies will be in achieving the same knowledge gain as is seen with conventional paper map use. Therefore the ability to read a paper map (as well as to use common sense) is necessary despite technological advances that attempt to ease our wayfinding burdens. Given this continued importance of map-use abilities, I now turn to a review of the literature on developing survey knowledge, developing map-use abilities, methods for the study of map use, map-use effects on the development of a survey perspective, implicit knowledge as it might relate to map use, and the predictive power of traditional spatial tests.

Developing a survey perspective. Thus far I have discussed the notion that maps can influence spatial thought broadly. However, spatial thought can encompass many skills and mental representations. There are a variety of frameworks for spatial thought and a common component of most frameworks is that survey knowledge is the most flexible and adaptive form of processing large-scale spatial information (See Table 1 for brief definitions of survey knowledge and other terms and measures used throughout this paper). Survey knowledge has also been labeled configurational knowledge (Montello, 1998), or a cognitive map (Downs & Stea, 1973). Cognitive maps have been defined by Downs and Stea as "a series of psychological transformations by which an individual acquires, codes, stores, recalls and decodes information about the relative locations and attributes of phenomena in the everyday spatial environment" (pg. 9). Likewise, configurational knowledge has been described as incorporating landmarks, routes, and linkages into a whole bound by some frame of reference (Golledge, Dougherty, & Bell, 1995; Ishikawa & Montello, 2006; Montello, 1998). Though there is evidence of hippocampal place and orientation cells that fire in specific locations and facing directions (e.g. Taube, Muller, & Ranck Jr., 1990), none of the authors discussed above, including Downs and Stea, make the argument that we actually have maps in our heads. This is part of the reason for using the less loaded terms of configurational or survey knowledge. The key is not what this mental representation would actually look like if we were able to literally put what is in the mind on paper, but that it allows us to synthesize various pieces of spatial information in a way in which we understand relationships between multiple points in the environment, similar to the way in which a map allows us to do so.

The framework proposed by Siegel and White (1975) describes the developmental progression leading to survey knowledge as moving from landmark knowledge to route knowledge, and ultimately to survey knowledge which results from creating links between multiple landmarks and routes. One could think of moving to a new city or town. At first a few salient landmarks may be easily recognizable and form the basis for orienting one's self in the environment. As one learns the routes to and from work, the grocery store, the bank, and other locations one frequents, one may primarily think of the city in terms of these routes. Eventually, these routes and landmarks would be incorporated into a whole in which one understands the relationships among work, the grocery store, and the bank even though one may have never traveled from work to the bank directly.

Siegel and White's framework is very consistent with the framework that Piaget used to organize his work on spatial thinking. Piaget viewed spatial thinking as progressing from topological to projective and Euclidean concepts. Topological concepts involve relative judgments such as on, next to, etc. This parallels the use of landmarks in that landmark knowledge may help one determine where one is in relation to a given landmark, but it does not necessarily give one the ability to plan routes or know the metric relationships between points. Projective concepts involve the perspective being taken into account, as in when following a route one knows to take a left at a certain intersection when coming from one direction but to take a right when coming from the opposite direction. Euclidean concepts parallel survey knowledge in the Siegel and White framework in that Euclidean knowledge involves having a metric system for framing the space to understand distances and angles between points. This enables one to infer spatial relationships that have not been experienced. For example, with Euclidean concepts one is able to know the vector direction from one point to another despite not being able to see the target location and there being no direct route to it.

Montello (1998; Ishikawa & Montello, 2006) has made the argument that the development of survey knowledge is not stage-like as the previous frameworks suggest. Instead, Montello argues that the ability to process information about landmarks, routes, and the survey perspective of the space are always present to varying degrees and that various experiences can lead to an increased ability to use, and rely on, the survey perspective. Ishikawa and Montello (2006) point out there is little evidence for the qualitative progression of steps leading to survey knowledge when looked at microgenetically. Instead they point to evidence that has demonstrated the ability to make metric judgments within seconds or minutes of exposure to an environment. However, Cohen and Shuepfer (1980) have shown that children rely more on landmark cues and adults have been shown to be superior at tasks that require configurational knowledge. In their study, 2nd graders, 6th graders, and adults were asked to learn a route via a series of slides. Children were then asked to recall the route taken. When landmarks were not available on recall, 2nd graders showed a significantly greater decline in performance than did 6th graders. In addition, the 6th graders and the adults were more accurate at a test of configurational knowledge (sketching the space) with only adults being able to produce completely consistent configurational depictions of the route indicated. This study was replicated in a virtual environment by Schmelter, Jansen-Osmann, and Heil (2009). Somewhat contrary to these studies, Herman (1980) found evidence that even kindergarten children are able to create cognitive maps of spaces they navigate (albeit a small model town and not a large scale space). However, performance of 3rd graders exceeded that of kindergartners suggesting that although the ability is present early on it is not fully developed at an early age.

The evidence presented by Montello coupled with some support for the Siegel and White framework suggests that the ability to use landmark, route, and survey knowledge may be more continuous on a microgenetic scale where these abilities are evident to some degree almost immediately. However, the ability to rely on survey knowledge likely increases when taking a more global perspective as evidenced by the developmental literature described above showing that adults are more likely to use survey knowledge, whereas children rely more on landmarks. Regardless of the exact developmental trajectory, either global or microgenetic, all authors agree that survey or configurational mental representations are the most flexible solution to solving spatial problems. It is also apparent that the ability to think of space from a survey perspective appears early in life despite significant gains throughout adolescence and into adulthood.

Development of map use. The previous section discussed the ability to mentally represent a space in such a way that metric judgments can be made and that the spatial configuration can be mentally represented. In what ways do we develop the ability to use the physical representation of a map? Using a map effectively requires one to recognize that the map is a representation that stands for the space and is therefore distorted in one or more ways from the actual space, and it also requires knowledge about the spatial components involved in making a map (Liben, 2006, Liben & Myers, 2007). Specifically, the user needs to understand the map is at a certain scale, azimuth, and viewing angle in relation to the real world. Some researchers have demonstrated rudimentary map-like skills in toddlers (Newcombe & Huttenlocher, 2003 for review) and kindergartners (Presson, 1982) suggesting that the bases for later map use are budding early in life.

Although young children have been shown to possess some of the early building blocks, maps are symbols that can offer many challenges for children. Liben (2006), for example, summarizes research demonstrating children’s competencies and struggles with maps. According to Liben there are several characteristics of maps that users must understand and master to become proficient. First, children must understand the symbolic nature of maps, which is something that is present from a relatively early age (DeLoache, 1987). DeLoache demonstrated that preschoolers understand the ability of one thing to stand for another by hiding an object in a model room. The children were then asked to find the object in a real room that was identical to the model room save for size. Despite the early presence of this ability it is certainly not mastered by preschoolers. In fact, 8-year-olds have been shown to demonstrate difficulties in interpreting map symbols when the symbol conflicts conceptually in some way with the referent. For example, it is harder to recognize that green rather than red dots can stand for fire trucks (Myers & Liben, 2008).

In addition to the symbolic nature of maps, children must understand that a map shows a space at a particular scale, viewing angle, and azimuth. Work from Liben and Downs (1989) has demonstrated that some children struggle with these concepts despite knowing that a map shows the layout of a large space. For example, some children make mistakes with scale by thinking that images of buildings are too small to really be buildings, or that roads on the map can’t really be roads because they are too skinny to drive on. Others demonstrate difficulties with viewing angle by mistaking an aerial depiction of something as an elevation view of some entirely different object. Blaut (1991) has found that in general children around the age of 5 or 6 can at least recognize aerial photos as landscapes and can use them for “simulated”, or imagined, navigation tasks. Thus we see more evidence of some early competencies as well as difficulties for many children as they try to use maps appropriately.

Lastly, the map user must understand how they are situated in relation to the map and the space in order to accurately determine where they are both on the map and in the space (Liben & Myers, 2007). Liben and Myers present evidence showing children around 10 years of age are able to perform complex mapping tasks under certain conditions, but may struggle if the environment is too large or landmarks are too similar.

Some of the errors shown by children have been consistent with the Piagetian framework of topological, projective, and Euclidean space. It is easier for children, for example, to indicate on a map a location that can be identified topologically, such as a location on a statue when only one statue symbol appears on the map. However, it is more difficult to be precise when projective and/or Euclidean concepts are required (Kastens & Liben, 2007; Liben & Downs, 1993). It is not just children who struggle; many adults also have difficulties with these concepts and show large variability in the ability to find one's location and facing direction on a map (Liben, Myers, & Christensen, 2010; Liben, Myers, & Kastens, 2008). Consistent with these findings is evidence that 6-8 year olds are not able to give accurate route directions using a map, and only some 10-12 year olds are able to do so (Blades & Meldicott, 1992). Clearly some abilities are present early, but the ability to accurately relate reality to representation and vice versa undergoes protracted development and apparently is not even mastered by many adults.

Methods to study map use. How are these mapping abilities tested by researchers? Liben (1997) identified four main methods for the study of map use. These methods, depicted in Figure 1, are comprehension, production, representational correspondence, and meta-representational methods. Comprehension tasks involve translating information from the map to the real space (e.g., navigating a route indicated by the map, or finding hidden objects based on map symbols). Production tasks involve the creation of a map or addition of information to an existing map based on exploration of the referent space (e.g., placing symbols on a map to indicate landmarks). Representational correspondence refers to tasks that require the child to relate one spatial representation to another of the same space (e.g., relating a picture of a given environment to a map of the same space). Finally, meta-representational tasks involve reflecting on relationships present in or revealed by referent-representation links.

The focus in the present study is on comprehension and production tasks. These tasks involve the direct use of a map to complete a goal in the real world, which is why they are of interest here. Some authors, including Liben (1997), have suggested that comprehension and production tasks are equivalent, that is, suggesting that performance across the two should be similar and involve similar underlying processes. Liben supports this by comparing Bluestein and Acredolo (1979) with Liben and Yekel (1996) and pointing out that performance on a comprehension task in Bluestein and Acredolo was similar to that in a production task used in Liben and Yekel. However, these studies used different spaces and had very different goals. Therefore, the procedures differed in a number of ways other than just whether they were comprehension versus production. Bluestein and Acredolo were interested in children's performance under various conditions of map alignment and misalignment, as well as the interaction of alignment with whether participants stood within the test space or looked in from the periphery. Liben and Yekel, on the other hand, were interested in the vantage point the children were afforded to view the space (eye level vs. an oblique angle) and the type of map used for the task (oblique vs. plan view). Given these differences, it is difficult to directly compare these studies to determine that comprehension and production tasks rely on the same processes and result in similar performance.

Other evidence (also noted by Liben, 1997) has suggested that comprehension and production tasks may not be equivalent. Siegel, Herman, Allen, and Kirasic (1979) had children explore either a large- or small-scale model town and then reconstruct the layout of the town in either the same scale they initially learned the environment or in the novel scale. The authors found that performance was best when construction was done on the same scale as exploration and that performance was worst when the small-scale was the learning environment and then construction occurred on the large-scale. Going from small-scale to large-scale is roughly similar to comprehension tasks, whereas going from large-scale to small-scale is similar to production tasks. While this study used models instead of maps, it does provide suggestive evidence that comprehension and production tasks may not be equivalent. However, DeLoache's work (e.g., DeLoache, Miller, & Rosengren, 1997) has not found consistent differences between going from model to space or from space to model. One of the goals of the present study is to investigate directly if comprehension and production tasks using maps result in similar or different performance as opposed to relying on literature that either does not directly address the question or uses a different symbolic medium other than maps.

Influence of maps on survey knowledge. Thus far I have discussed the development of cognitive maps (or survey knowledge), the ability to use a physical map, and the methods used to study map-use abilities. What evidence is there to show that the use of physical maps can lead to the acquisition of survey knowledge? It is clear from a variety of studies that the use of maps does indeed aid in the acquisition of survey knowledge. Thorndyke and Hayes-Roth (1982) found that with moderate exposure to maps and navigating an environment, adults developed better survey knowledge from map learning than from direct navigation. However, they also found that with prolonged exposure, the advantage of the map over direct navigation disappeared. This suggests that map use may be beneficial for initially learning an environment, but enough direct experience with the environment will lead to accurate survey knowledge as well. However, focusing on a goal such as a specific target location can inhibit the acquisition of survey knowledge from direct experience (Rossano & Reardon, 1999). It is not clear whether goal-oriented behavior during map use would also prevent survey knowledge acquisition and it is important to keep the results from Rossano and Reardon in mind when investigating how maps influence survey knowledge acquisition.

Somewhat contrary to these data, Gollege, Dougherty, and Bell (1995) found only weak evidence that using a map was superior to participating in a virtual walk through an environment. Similarly, Richardson, Montello, and Hegarty (1999) found that there were no significant differences in survey knowledge between those who learned a complex building from direct experience versus those who learned from a map. However, they did find that both of these methods were superior to learning in a virtual environment. Others have found that coupling virtual experience with map use does not result in improved performance (Goerger, et al., 1998).

The sum of this work tells us that maps are likely useful for quickly acquiring configurational knowledge about a space. Even if prolonged navigation of a space can give the same results, maps can certainly facilitate the process. The literature discussed thus far does not address whether children are able to acquire survey knowledge through maps. I now turn to literature that has attempted to determine if the findings with adults are mirrored with children.

Although, as stated earlier, children do struggle to master the ability to use maps effectively despite early evidence of core competencies, there are several lines of work suggesting that having a child use a map results in learning about the environment which is not necessarily achieved if the overhead perspective is not shown (Liben, 2006; Uttal 2000). Uttal cites evidence of children being able to navigate more effectively through mazes or around obstacles at a very young age—even infancy in some cases—when being able to view the space from an aerial perspective. He goes on to discuss work from his own lab that demonstrates preschoolers (4- to 5-year-olds) were able to perform more accurately in recalling relationships between places when a map was used instead of flash cards. Maps display the relationships among locations simultaneously, while flashcards show these relationships in sequential order. In this study the children were specifically asked to learn the layout of 6 rooms that contained stuffed animals either by studying a map or through sequentially presented flashcards. The children were then placed in the space and as they moved from room to room they were asked what animal would be behind the various doors. Those children who had used a map to learn the space outperformed those who learned the room contents by sequential presentation of the relevant information. Uttal is quick to admit that this work was conducted in a very small-scale space and that further work is needed to determine if these findings would be replicated on a larger scale. The scale is an issue not only because of the sheer size of the space, but also because both the space and the map that were used were very simple and symmetrical. In addition, the children were specifically asked to learn the layout of the objects rather than to perform some other goal, such as navigating from one point to another. Though learning a spatial layout is one use of maps, maps are useful in other goal directed behaviors, such as comprehension and production tasks. It may be more interesting to know if these uses also lead to accurate survey knowledge. That is, can survey knowledge be gained when survey knowledge is not the immediate and explicit goal? The next section discusses what is known about incidental learning as it relates to map use.

Incidental knowledge and map use. Incidental knowledge as referred to here is related to the conceptualization of learning and memory proposed by Hagen and Stanovich (1977) in which they differentiated between central and incidental memory. In Hagen and Stanovich's work they presented children with cards containing two classes of data (e.g., animals and pieces of furniture). Children were asked to pay attention to one of the classes (e.g., to remember the animals) but were later tested on their memory for both classes of information. Central memory refers to how well they were able to remember the class of information they were told to attend to (here, animals) and incidental memory refers to the other class of information that they were not explicitly attending to (furniture in the present example).

In the spatial realm it has been shown that survey knowledge is more difficult to acquire incidentally than route knowledge (van Asselen, Fritschy, & Postma, 2006), consistent with the Siegel and White (1975) framework. In their study, van Asselen et al. had participants walk a route either with the explicit instruction that the study was on route learning and therefore the route should be attended to, or simply because a mistake in the study location had been made and therefore no explicit instruction to attend to the route was given to this second group. Results showed that those in the explicit group drew more accurate sketch-maps and were more accurate at a route reversal task than the implicit group, while other measures testing route knowledge showed no difference between learning conditions. This would suggest that survey knowledge is unlikely to be gained implicitly. This is consistent with the results from Rossano and Reardon (1999) showing that when participants were asked to focus on a goal while navigating an environment they performed less well on tests of survey knowledge compared to those who were not goal directed.

Although these studies demonstrate the difficulty of implicitly learning the survey perspective, these studies did not use maps in the learning process. In fact, while there are ample studies demonstrating the use of a map can lead to survey knowledge (Goerger, et al., 1998; Liben, 2006; Thorndyke and Hayes-Roth, 1982; Uttal, 2000) these studies almost always explicitly instruct the participants to learn the environment. Although this goal is certainly a legitimate one for map use, maps are often used for reasons other than to learn the configuration of a space. Therefore the procedures used in this study investigate the incidental acquisition of survey knowledge in a context in which children are asked to perform tasks similar to those for which maps are typically used.

Measuring survey knowledge. Various tasks have been used in the extant literature to measure survey knowledge. These include tests asking participants what objects and landmarks to expect to see in relation to other objects and landmarks (e.g. Uttal, 2006), drawing sketch-maps of the environment (e.g. van Asselen, Fritschy, & Postma, 2006), pointing to unseen locations (e.g. Bryant, 1982), and taking the shortest route back to a target (e.g. Krieg-Brückner, Röfer, Carmesin, & Müller, 1998).

The two tasks used in this study were a pointing task and a shortest route-to-target task. The pointing task was based on work from Hardwick, McIntyre, and Pick (1976) in which children pointed from three locations to unseen targets. Anooshian and Young (1981) later found that a similar task in a larger scale environment resulted in extremely poor performance (i.e. lines that did not intersect from the three locations). These authors therefore used four target locations and it is for this reason that four locations were used in the present study.

Krieg-Brückner, Röfer, Carmesin, and Müller (1998) identified a shortcut to target task in their taxonomy of spatial knowledge required for navigation. This task involves taking the shortest route back to a target. One must use survey knowledge to complete this task because it requires taking a previously untraveled route. Therefore one must understand where the target is in relation to the starting position and determine the shortest trajectory to get there, thus needing to understand the relationship among various points in the environment.

The above constructs of map use and the acquisition of survey knowledge are likely at least somewhat dependent on some fundamental spatial skills that have often been measured by the use of paper-and-pencil laboratory measures. Next I address what the literature tells us in regard to how these small-scale measures relate to large-scale mapping and navigation tasks.

Predicting environmental performance with small-scale laboratory tasks. Evidence regarding the predictive ability of traditional paper-and-pencil laboratory tasks of spatial ability on large-scale spatial tasks is somewhat mixed. A factor analytic approach (Allen, Kirasic, Dobson, Long, and Beck, 1996) concluded that while laboratory tests and environmental tests occupy distinct factors of spatial ability, small-scale tests may be used to predict performance on the environmental measures.

Hegarty, Richardson, Montello, Ishikawa, and Lovelace (2006) were more conservative in the endorsement of predicting environmental skills with paper-and-pencil tasks. The authors did find that there was some overlap in variance between the two types of tests. However, they found that the link was stronger when a virtual environment or video media was used instead of tests in a real environment. Contrary to this finding Liben, Myers, and Christensen (2010) found that basic spatial skills were predictive of performance in both a real environment and in a representational medium, albeit with different individual tasks providing the predictive power in relation to environmental performance and representational performance.

Determining if it is possible to predict performance with easily administered laboratory tasks has implications for pedagogy because students in need of spatial education could potentially be identified without having to leave the classroom. Understanding the ability to predict general spatial performance with laboratory tasks is also important for researchers in order to know if predicting performance can be done accurately within the lab.

There have been various attempts to classify the types of spatial skills that can be measured by laboratory tasks. One such classification system was established through a meta-analysis conducted by Linn and Petersen (1985). They identified three categories of spatial skills and tasks to measure those skills: spatial perception, mental rotation, and spatial visualization. Spatial perception involves judging spatial relationships to the self while ignoring conflicting frames of reference. Tasks that measure this skill include the water level task (WLT) and the rod and frame task (RFT). Mental rotation is a fairly self-descriptive category as it requires individuals to quickly rotate objects in their minds. There are various 2-dimensional and 3-dimensional versions of the mental rotation task (MRT). Spatial visualization is defined by Linn and Petersen as requiring "complicated, multi-step manipulations of spatially presented information" (p. 1184). They emphasize that these problems can rely on some of the same processes as spatial perception and mental rotation tasks, but have the possibility of multiple solution strategies. Tasks falling under the spatial visualization category include the paper folding task (PFT) and hidden pictures task (HPT). The present study uses the WLT, a 2D MRT, the PFT, and the HPT to measure individual spatial skill. The specific measures used are described more fully in the method section.

Research Questions and Hypotheses

Given this theoretical background and the gaps discussed in the map-use literature, the present research addresses four main questions. I discuss each question with specific hypotheses below.

Performance on comprehension and productions tasks. First, does performance differ between comprehension and production tasks? That is, are children able to place flags in the space more or less accurately than placing stickers on a map? I predict that those who complete a comprehension task will be more accurate than those who complete a production task. This difference is predicted because, as I describe below, I expect the comprehension task to elicit a different pattern of strategy behaviors as compared to the production task. A different pattern of strategies should occur because the comprehension group has the location information in front of them on the map at all times, whereas the production group begins with a blank map, thus the comprehension group can better plan how to navigate the environment.

Strategy use. The second question is, in what ways do observable strategies differ between the comprehension and production tasks? As mentioned above I predict differences in the observable strategies used as each task makes different information available to the child. Specifically, I hypothesize that children completing the comprehension task will show a greater use of strategies such as looking at the map, aligning the map, touching and tracing the map, turning the map, and pointing to the space. I predict more (or a greater proportion of) strategy use from the comprehension group because they will be more likely to use the information they have on the map to plan their routes through the environment and will therefore be more likely to use the map to keep track of their location. Efficiency in time and minimizing route distance to complete the task would support the hypothesis that children in the comprehension group are doing more planning.

Relating strategy use and performance. As stated above I hypothesize that the comprehension group will show better placement accuracy and that the comprehension group will also exhibit more strategy use. I further hypothesize that the effect of task on performance will be mediated by strategy use. That is, the comprehension group will demonstrate more strategy use, which will then predict performance.

Survey knowledge acquisition. The third question is will children completing the mapping tasks demonstrate better survey knowledge of the environment as compared to the no-map group? Based on the literature cited above, I hypothesize that the children who complete the mapping tasks will demonstrate better survey knowledge as measured by the pointing task as well as the route-to-target task. I do not have any strong predictions regarding differences in survey knowledge between the comprehension and production conditions. However, if there is to be a difference I would predict that the comprehension group should once again perform better than the production group as increased strategy use and better performance on the placement task should be associated with acquiring a better knowledge of the environment.

Individual differences in spatial ability. Lastly, how do laboratory measures of spatial ability relate to the various outcome measures? In general I hypothesize that spatial ability will be positively associated with performance on each task. Specifically, I predict those with better spatial skills to perform better on the placement task, to exhibit more strategies, and to perform better on the measures of survey knowledge. What is of particular interest is to determine if the relationships described in the hypotheses for the first three questions are robust enough to be evident even when controlling for spatial skill.

In addition, I investigate sex differences in relation to the various outcome measures. Previous work using similar tasks has found that boys and men typically outperform girls and women on these tasks (Liben & Myers, submitted). However, in this work it has also been found that sex does not always predict performance when other variables, such as spatial ability, are controlled for (Liben, Myers, & Christensen, 2010; Liben, Myers, & Kastens, 2008). The present study attempts to replicate and extend these findings. I predict that the previous work will be replicated in that effects of sex will not be present when controlling for other variables.

Chapter 2

Method

Participants

Fifty-eight typically developing children (28 girls, 30 boys) between the ages of 9 and 10 years old were recruited through the Families Interested in Research Studies (FIRSt) Database at Penn State. Parents were contacted by letter and telephone to determine interest in the study. The age range in months for girls was 110 – 131 (M = 120.5, SD = 6.8) and for boys, 108 – 120 (M = 120.2, SD = 7.0). Mirroring the demographics of the area (surrounding Penn State University) the sample was almost entirely Caucasian, thus limiting the ability to generalize results to a broader population. All testing took place in the summer of 2010 when the undergraduate presence on campus is minimal, opening up the environment for relatively interference-free testing. Parent consent and child verbal assent were obtained prior to each child participating in the study, using procedures approved by the Institutional Review Board. All children received a gift certificate for a free ice cream cone worth approximately $2 for participating in the study. Children were assigned to one of three conditions, production (N = 19), comprehension (N = 19), or no map (N = 20), which are described below. Assignment was done as randomly as possible while ensuring sex and age were relatively balanced across the three conditions (see Table 2 for distribution of sex and age across the three conditions).

Procedures and Materials

After obtaining parental consent and child assent, the children were asked to wear a point-of-view (POV) camera. This camera was embedded in the nose bridge of a pair of sunglasses. The lenses were removed from the sunglasses because in pilot testing the lenses pressed against the cheeks of some of the children causing discomfort. This camera was used to record the general gaze of the participants (i.e. at the map or the surroundings). The children were then led to the testing area on campus (see Figure 2 for a map of the area). The testing site was chosen for several reasons. It is easily defined on all four sides by two-lane roads and is typically quiet, with few pedestrians. The area is also relatively complex with multiple levels and areas separated by buildings. Pragmatically, it is located close to the psychology building and was therefore convenient and easily accessed. It should be noted that a portion of the area was closed for construction throughout the entire data collection process (see Figure 3). There was also some construction that took place for a little over half of the children in the center of the map area. This construction did not prohibit movement from one area to another, but it did limit the path choices that were available. While these circumstances were spread relatively evenly across conditions, analyses were performed (reported in results) to address the concern that systematic patterns in the data may be associated with the amount of construction taking place during testing.

Orientation to the testing area. Upon entering the testing area, the POV camera was started. The researcher then led the children on an initial walkthrough of the area (the path of this walkthrough is shown in Figure 4). At the beginning of this walkthrough the children were told that there were only two rules, that they should not cross any of the roads and that they should not go into any buildings. They were told that walking through parking lots was allowed and that there were some passageways that led under the buildings, but they were not to cross two-lane roads or go through any doors into buildings. The experimenter took each child along the same route, enabling them to see the area they were allowed to explore as well as the roads they were not allowed to cross. This was done (1) to ensure that each child had at least a baseline level of exposure to the entire environment, even if they did not explore the entire environment during the mapping task, and (2) to provide the opportunity to introduce a target location to be used for the pointing and route tasks that occurred after the flag and sticker placement task was complete. This target was established by placing a penny at a specific point on the ground (indicated in Figure 1). The children were told that part of the game we would be playing was to see if anybody would pick up the penny while we were doing the other activities outside. The children were asked to look around and remember where the penny was so they could find it at the very end. The spot with the penny was revisited toward the end of the walkthrough as a loop was completed. Every child recognized the area as where the penny was left either spontaneously when passed by the second time or when prompted by the experimenter. If the penny had been picked up during the initial walkthrough a new penny was put down in the same spot (this happened for fewer than 10 percent of the children).

All children were then led to the same start location facing in the same direction (shown in Figure 1). The researcher then gave one of three sets of instructions depending on condition. Children in both comprehension and production conditions were given a map printed on standard letter sized (216 mm X 279 mm) paper with a scale of approximately 1000:1. The maps were attached to a large foam board measuring 58.4 cm by 43.2 cm. The borders of the foam board were color- and pattern-coded to facilitate later coding of map orientation. The large board was used rather than a standard clipboard because pilot testing showed that the map was not always caught by the POV camera frame even when a child was looking down at the map. This board ensured that at least part of the board was in view whenever the child looked down at the map. The map was then handed to the child so that it was aligned with the environment. At this time a small keychain-sized camera that was affixed to the map was started in order to capture any touching or tracing that children did on the map surface.

Completing flag and sticker placement task. Next the researcher pointed out where the child was standing (indicated by an “X” on the map) and explained to the child that the black objects represented buildings and the gray and white lines indicated roads and sidewalks. Children were not told that the map was aligned or which direction they were facing on the map. If at any time during testing a child asked where they or anything else were currently located on the map, the experimenter told them that they should just do the best they could with the information they have. While the exact number of children that asked such questions was not recorded, it was fewer than 10 individuals that asked pointed questions regarding where they were in relation to the map.

The map for children in the comprehension condition had stickers already on the map and the children were told they would need to place the colored flags provided by the researcher in the locations in the real world so that someone using the map could find where they put their flags. This is similar to using a map to navigate to various points of interest. Those in the production condition were given a blank map and then told that there were six colored flags placed throughout the environment that they needed to find. Each time they found a flag they would use the colored dots provided to indicate where on the map the flag was in such a way that someone could use their map to find where the flags had been. This would be similar to finding oneself on a tourist map in an unfamiliar city. In the no-map condition children were told that they had to find the six flags and that each time they found a flag they would find a clue to a riddle that they would be able to try to solve once they had all the clues. These tasks were based on a variation of the production task used with this age range in previous work (Kastens & Liben, 2007; Liben, 2009; Liben & Myers, submitted). The flags used for the flag and sticker placement task consisted of red, green, blue, black, white, and yellow colored fabric. Figure 5 shows the flags in situ and Figure 1 shows the location of the stickers and flags. There are two notes to make about the flag locations. First, the locations were identical across all conditions. This means that the dot locations for the comprehension condition marked the exact locations the flags were placed in the production and no-map conditions. Second, despite appearances on the map, flags were not visible from one another due to vegetation, or differences in elevation. The dots used to indicate flag locations matched the flag colors and were 0.6 cm in diameter.

The flag and sticker placement task was then started with the researcher following the child with a hand-held camera to record any observable strategies that would not be picked up by either the POV or map camera. This was also done so that if any technical problems occurred with the other cameras, most behaviors would still be able to be coded from the experimenter's hand-held camera. The children were allowed to explore the environment freely. The researcher intervened only if a child attempted to cross a street that would take them out of the testing area or if they attempted to go into any buildings (only one or two children attempted to do so). There were a few rare cases in the production and no-map conditions in which the children were not exploring all the areas on their own and were therefore not finding all the flags. If a child continued to walk through the same areas without exploring areas where flags were located, the experimenter simply suggested walking in a certain direction (this was the case for fewer than 20% of the children in these two groups). At no point did the experimenter provide any information about corresponding positions on the map.

Assessing survey knowledge. Upon completing the flag and sticker placement task (i.e., by either finding all of the flags and placing stickers on the map, by putting the flags in the space as indicated by the map, or by finding all of the flags and clues to the riddle), each child then completed two measures of their survey knowledge of the space. The first test of survey knowledge was a pointing task. The children were led to four specific locations in a fixed order and along a fixed path between locations (Figure 6 shows the locations and the path taken). At each location a spinner was placed at a specific point on the ground and the child was asked to use the spinner to point in a straight line to where the penny was placed during the walkthrough. They were asked to imagine there were no buildings in the way or that they could fly over the buildings so they could go in a perfectly straight line. The spinner used consisted of a disc with a freely rotating arrow and 48 equally spaced numbers around the outside edge of the spinner. Thus the space between each number was 7.5°. This task is modeled after Hardwick, McIntyre, and Pick (1976). Four positions were used instead of three as was done in the Hardwick et al. study because Anooshian and Young (1981) found that in a space much larger than that used by Hardwick et al. children's pointing vectors did not always intersect. Scoring for this task is discussed below.

After the final pointing position, children were then told it was time to see if the penny was "where we left it". They were asked to lead the way back to the penny by walking the shortest way they could think of, so they took as few steps as possible. (A few children tried to take really big steps, or count their steps. These individuals were told not to worry about counting steps, just to go the shortest way possible). As the child walked the researcher traced the path on a blank map of the space. All but 3 children were able to find the penny on their own.

Laboratory spatial measures. Upon reaching the penny, children were then led back to the lab to complete the paper-and-pencil spatial tasks. As mentioned earlier the spatial tasks used in this study were the water level task (WLT), a 2D mental rotation task (MRT), the paper folding task (PFT), and the hidden pictures task (HPT). These cover the three categories of spatial skill as defined by Linn and Petersen (1985) described above and have been used in similar research with children and adults (Liben, Kastens, & Christensen, 2011; Liben & Myers, submitted; Liben, Myers, & Christensen, 2010; Liben, Myers, & Kastens, 2008). The WLT consisted of 6 drawings of rectangular bottles tipped 30°, 45°, and 60° from upright to both the left and the right (Liben, 1995). Children were asked to draw a line to show what the surface of the water would look like if the bottle were half full and held in the positions shown. There was no time limit on the WLT. The MRT was the 2D task used in the Primary Mental Abilities of Thurstone (1962). This task required children to identify items that would match a series of target items if they were only rotated and not reflected (i.e. flipped). Children were given 2 min to complete as much of the MRT as possible. The PFT used here was originally developed by Ekstrom, French, and Harman (1976). This task illustrates pieces of paper being folded and a hole being punched through all the layers of folded paper. For each item the child then needs to identify the pattern of the holes once the paper is completely unfolded. Children had 5 min to work on the PFT. The HPT was adapted from the Group Embedded Figures Test and the Children's Embedded Figures Test developed by Witkin and Goodenough (1981). For each item of the HPT children were asked to trace the outline of a target shape. Children had 2 min to complete as much of the HPT as they could. These tasks were given in a fixed order: WLT, followed by the MRT, the PFT, and lastly the HPT.

Coding of paper-and-pencil spatial tasks. For the analyses below the spatial tasks were coded in the following ways. For the WLT the degree error (i.e. the degree that each of the participant lines deviated from horizontal) was measured for each of the six bottles. Consistent with Sholl and Liben (1995), the number of items within 10 degrees of horizontal was then used as the dependent measure. For the MRT, participants received full credit for any correct answers chosen on a line as long as no incorrect responses were also chosen. If any incorrect responses were chosen for a particular item the participant received 0 points for that item. The PFT was similarly adjusted for guessing by taking the total correct and subtracting $1/4^{th}$ of the incorrect responses. For the HPT the total correct was used as the dependent measure.

Coding of flag and sticker locations. Sticker locations were measured in X, Y coordinates to be used in a bidimensional regression described in the results section. To make scoring equivalent between the two groups, maps were created for the comprehension group that indicated their flag placements with the same stickers used for the production task. Thus all children had a map with the six colored dots indicating their answers. These locations were marked live as the children placed their flags. To ensure the accuracy of the live scoring, 10 (56%) maps from the comprehension group were double coded by an experimenter not involved in the live testing using the video recordings. Comparing the coordinates from this second coding to the live coding coordinates showed excellent reliability. The interclass correlation was .998. The average difference between the two scorings was 3 mm. With the map scale being approximately 1000:1 the 3 mm difference on the map translates into 30 cm in real space. There were only two coordinates with a difference greater than 1 cm (1.6 cm and 1.8 cm respectively), with the majority (88%) falling under 5 mm.

An alternative coding system was also used for the flag and sticker locations similar to that used by Liben and Downs (1993). Scoring was done on a 4 point scale where a score of 4 indicates that the participant’s dot at least partially overlapped with the correct placement of the dot. Four concentric rings each adding the equivalent of the dot diameter to the previous ring were used to determine accuracy when the placement did not overlap with the correct answer. Thus, a placement within 1 diameter from the correct answer got a score of 3, within 2 diameters a score of 2, within 3 diameters a score of 1, and anything farther than that received a score of 0.

Scores were then averaged over the 6 locations to provide the dependent variable for analysis. The specific results from this scoring procedure are not reported here as they mirrored the same pattern of results as the bidimensional regression measures and the two measures were highly correlated, r(36) = -.87, $p < .001$.

Coding of map strategies. As stated earlier, children's actions were recorded by a camera held by the experimenter, a POV camera that the children wore, and the small keychain camera that recorded the map if a map was used. Some technical problems led to some missing video data. There were four children who did not have data from the POV camera, four who did not have data from the map camera, two who did not have data from the POV or map camera, and one who was missing most of the hand-held camera view. In each of these situations the information available from the other camera angles was sufficient for coding the entire portion of the study involving the flag and sticker placement. All three camera angles (or as many as were available) were edited to be included in one frame in a split screen format. This is illustrated in Figure 7.

Video coding was done using Interact® coding software from Mangold International. The coding was aimed at elucidating the observable strategies that the children used while completing the task. A duration code was created for the amount of time looking at the map (as compared to looking at the environment). Although many children held the map out in front of them the entire time, the video data provided enough information to determine whether the child was actually looking at the map. Another duration code indicated when the children had the map aligned with the space. These two codes were also able to be combined to indicate how much time was spent looking at the map when it was aligned with the space. A third duration code was used to indicate when children were touching the map. The touching code included static pointing to locations as well as tracing routes on the map. There were two frequency codes created, one for turning the map in relation to the body of the participant and another for pointing to things in the environment.

Data from the Interact files were extracted using ActSds and reliability for the strategy coding was calculated using GSEQ (Bakeman & Quera, 2008; Bakeman, Quera, & Gnisci, 2009). These programs are specifically designed for extracting data from Interact and calculating appropriate kappa values. A total of 12 (32%) of the map task videos (split equally between comprehension and production) were coded by a second independent observer. GSEQ calculates kappa based on whether it is a duration or frequency code. For all codes a window of plus or minus 1 s was used for aligning the start times of codes. For duration codes the two observer codes had to overlap by at least 75% to be in agreement. Kappa values for each individual code can be found in Table 3. Combining the three duration codes (alignment, looking, and touching) resulted in a kappa of .82. The kappa for the two frequency codes (turns and pointing) was .61. Therefore all kappa values were in what is typically considered an acceptable range.

Other codes included under the heading of strategies are task duration, distance traveled while completing the task, and order in which the flags were found or placed. These are included to show potential differences in the demands the tasks place on the individual and the patterns of behavior the tasks elicit.

Chapter 3

Results

The following results are broken into four major sections corresponding to the four questions of interest. The first section addresses the preliminary analyses done to determine if the sidewalk construction that took place for a subset of children had any effect on any of the variables of interest. The first section then discusses results which compare the performance of sticker and flag placement between the comprehension and production groups. The second section looks at the measures of survey knowledge to determine if there are any differences among the three groups. The third section discusses strategy differences between comprehension and production conditions. These strategies include the observable strategies from the various video recordings as well as data on time to complete the task, distance traveled during the task, and orders in which children visited the flag locations. The fourth section addresses how individual differences in spatial skill are related to performance, survey knowledge, and strategy use. Table 4 summarizes the main findings across these analyses and Table 5 presents the Ms and SDs for each of the variables discussed below.

Comparing Performance

In order to compare performance between the comprehension and production task, the X, Y coordinates of each sticker or flag placement were recorded by measuring to the center of the sticker for each placement. As mentioned above, the experimenter indicated the flag placement locations for the comprehension condition so all children in the two map-use conditions had a map with 6 sticker locations. Figure 8 presents composite maps for each flag collapsed across all participants, split by sex and by condition.

To score the accuracy of each individual's responses, bidimensional regression was used in the manner suggested by Friedman and Kohler (2003). Bidimensional regression works similarly to linear regression, but is customized for two-dimensional data. Running a bidimensional regression provides several indicators for each individual's set of responses. The first parameter, the distortion index (DI), indicates the overall fit of the participant's configuration to the real configuration. This is somewhat analogous to the amount of unexplained variance in traditional regression and is scaled in such a way that it is independent of the data so that comparisons can be made across different configurations and data sets. The second of these parameters is a measure of how accurately the scale of the participant's map matches that of the actual answers, labeled scale from this point on. A score of 1 on scale would indicate the participant's answers were of the same scale as the correct answers. Scores less than 1 on the scale measure indicate a contraction of the space, whereas scores greater than 1 indicate an expansion of the space. The last indicator is a measure of the degree to which participant's answers are rotated relative to the correct configuration and is labeled theta (θ). The θ values were adjusted such that values used in the analyses reported below indicate absolute deviation from the correct orientation between 0° and 180°.

As described by Friedman and Kohler, one of the advantages to bidimensional regression is that it determines the fit of the entire configuration instead of the individual locations. In addition, the scale and θ parameters offer more detail as to the characteristics of distorted layouts. These properties of bidimensional regression are what make it a more desirable measure than the target scoring system described above. Bidimensional regression does not account for the fact that errors from location to location may be correlated, which could result in incorrectly determining that a participant's locations are significantly related to the correct locations. However, in the present data the parameters are being used to determine group differences in overall fit of the configurations and not to determine if the relationships to the correct configuration are greater than zero, therefore the problem of correlated errors should not influence the interpretation of the results reported here.

Before turning to the analyses of central interest I first address the issue of the sidewalk construction present in the environment. As noted earlier, some additional construction took place in the testing area for some of the children, beyond the construction work that was ongoing throughout the entire study. Table 6 shows the distribution of participants based on sex and condition that were tested during this construction vs. when this construction had not begun or was complete. A series of 2 (sex) X 2 (condition) X 2 (construction) ANOVAs were run to determine if the presence of construction had an influence on participant performance. The dependent variables used in these ANOVAs were, respectively, DI, pointing mean error, route-to-target distance, distance traveled during task, and task duration. The only significant effect for construction occurred when DI was the dependent variable. This was a main effect of construction, $F(1,30) = 5.38$, $p = .027$, $\eta_p^2 = .15$. Those that were tested when the additional construction was ongoing performed better on the placement task than those who were tested without the additional construction, with DI Ms (SDs) respectively of, 33.4 (25.9) and 53.9 (32.0). There were no interactions of construction with either sex or condition.

Because there were no interactions and because participant group and sex was distributed relatively evenly across the presence and absence of this additional construction (as seen in Table 6), the construction variable was not included in the other analyses involving DI discussed below. Because there were no effects or interactions on any of the other variables, the construction variable was also not used in any of the other analyses. Reasons and implications of the main effect of construction on DI are addressed in the discussion section.

After determining that the presence or absence of construction could be left out from subsequent analyses, the DI, scale, and θ parameters were used in three separate 2 (condition) X 2 (sex) ANOVAs to determine if there were any group differences. (Note that the no-map condition is not included because children in that condition did not complete a placement task). The analysis with DI as the dependent variable resulted in a significant main effect of sex, $F(1, 34) = 4.63$, $p = .039$, $\eta_p^2 = .12$, where boys had significantly lower DIs on average (indicative of better performance) than girls. Means (SDs) for boys and girls, respectively, were 32.9 (27.0) and 52.2 (30.6). There was also a significant main effect of condition, $F(1,34) = 5.25$, $p = .028$, $\eta_p^2 = .13$, showing that the comprehension group performed significantly better than the production group, Ms (SDs) respectively, 31.8 (26.5) and 52.2 (30.5). See Figures 9 and 10 for graphs of these effects. There was no interaction between sex and condition on DI.

The ANOVAs on the scale and θ measures help give a better sense of where differences in overall DI come from. For the ANOVA on scale there was once again a significant main effect of sex, $F(1, 34) = 4.16$, $p = .049$, $\eta_p^2 = .12$, showing that girls contracted the layout to a greater degree than boys. Ms (SDs) for girls and boys respectively were, 0.70 (0.28) and 0.86 (0.24). There was also a main effect of condition, $F(1,34) = 4.88$, $p = .034$, $\eta_p^2 = .12$, indicating the production group on average contracted the layout to a greater degree than the comprehension group. Means (SDs) for the production and comprehension groups respectively were, 0.79 (0.28) and 0.87 (0.22). There was no significant interaction between sex and task on the scale measure.

For the ANOVA on θ there were no significant effects. However, the main effect of condition did approach significance, $F(1,34) = 3.62$, $p = .066$, $\eta_p^2 = .10$. This trend indicates that the production group rotated the array more than the comprehension group. Means (SDs) for the production and comprehension groups, respectively, were: 27.1 (33.2) and 11.0 (14.2).

This series of analyses show that there are significant differences between boys and girls as well as between conditions in regard to performance on placing the flags and stickers. It appears that these differences mainly result from more contraction of the layout by girls and the production group, with some evidence of increased rotation by the production group as well. See Figure 11 for a graphical illustration of contraction from select participants.

Comparing Survey Knowledge

To review, the two measures of survey knowledge used here were a pointing task and a route-to-target task. In order to identify any group differences for these measures, two separate 2 (sex) X 3 (condition) ANOVAs were run. (Note that the no-map group is now included in the analysis because all participants completed these measures of survey knowledge.) The hypothesis that map use leads to better survey knowledge is only supported if one or both of the map-use conditions show better survey knowledge than the no-map condition.

The dependent measure for the pointing task ANOVA was the absolute error averaged across the four pointing locations for each participant. Results from this ANOVA indicated no significant main effects or interactions. The mean error for the entire sample was 40.5° with a standard deviation of 27.7°. A modified Reyleigh V-test was conducted on the responses for each location as described in Kanji (2006) and Sholl (1989). The V-test is a statistical test for randomness around a given angle. Rejection of the null hypothesis is indicative that the responses do indeed cluster around the angle. For each location the test was run to determine if the answers clustered around the correct answer (255° for location 1, 307.5° for location 2, 7.5° for location 3, and 330° for location 4). In each instance the significance level was less than .05 indicating that the answers were not randomly distributed and indeed clustered around the correct answers. The implications of this test for the difficulty of the pointing task are addressed further in the discussion. Figure 12 shows the rose diagrams created for each of the four locations. The figures show the data pooled as well as split by condition and sex. A rose diagram can be read in the same way as a traditional histogram, but graphed in a circular field to more accurately represent the data.

As another way of looking at pointing performance, participant answers were marked as correct or incorrect within a given range of error. Windows of plus or minus 45° and plus or minus 90° were used. Table 7 shows the distributions of number of locations correct for each window. In an attempt to find any patterns in the poorly performing individuals I investigated if there were any obvious characteristics of the 12 children who had 3 or 4 locations incorrect in the 45° window and the 5 children who had 3 or 4 locations incorrect in the 90° window. There was, however, no apparent pattern in these data. These poorly performing individuals were relatively evenly spread across condition and sex and there was no apparent pattern with performance on the spatial ability measures (i.e. some of these individuals performed well and others poorly on the spatial tasks). Given the small number of children who performed this poorly on the pointing task, no formal statistics were computed to determine if there were other variables associated with these individuals.

For the route-to-target task the dependent measure was the distance walked from the final pointing location to the target. The route traveled was traced then measured using an opisometer (device used for measuring distances on a map) for each participant. The means reported here are scaled up from these measurements so that the number of m walked is reported as opposed to the length of the route in cm as measured on the map. Data was missing for one participant who gave up on the route-to-target task before traveling less than 20 m from the starting location. This ANOVA once again showed no significant effect of condition. There was, however, a significant main effect of sex, $F(1,51) = 5.84$, $p = .019$, $\eta_p^2 = .10$. As shown in Figure 13, this effect indicates that boys (M = 276 m, SD = 77 m) took significantly shorter routes back to the target than girls (M = 337 m, SD = 108 m). There was no significant interaction between sex and condition on route distances back to the target. Figure 14 displays a histogram of the path distances. Note the range of distances traveled back to the target was 190 m – 747 m.

Analyzing Strategy Use During Flag and Sticker Placement

As discussed in the method, there were a variety of measures used to look at strategy use during the tasks. I first discuss results related to distance traveled, flag and sticker order, and task duration because these measures (especially task duration) have implications for how the time spent using other strategies (i.e., looking at the map, aligning the map, turning the map, touching the map, and pointing in space) are analyzed and interpreted. The results are discussed in the following order: distance traveled during task, flag order, task duration, looking at the map, aligning the map, turning the map, touching the map, and pointing in space. After addressing these results individually, I address how various strategies are related to performance both on the task and on measures of survey knowledge.

Distance traveled. The distance traveled during the task was measured in the same way the route-to-target distances were measured above. These measurements were then used as the dependent measure in a 2 (sex) X 3 (condition) ANOVA. The only significant effect was condition, $F(2,52) = 9.21$, $p < .001$, $\eta_p^2 = .26$. Follow-up comparisons using a Bonferroni adjustment for multiple comparisons showed that the comprehension group traveled significantly shorter distances than both the production and no-map groups. Means (SDs) for these three groups, respectively, were, 731 m (162 m), 1,151 m (168 m), and 1,057 m (368 m). These results are depicted graphically in Figure 15. There was no significant difference between the production and no-map groups. Figure 16 displays a histogram of the distances traveled during the task. The range for the distance traveled while completing the task was 410 m – 1,623 m.

Flag order. The order in which the flags were found or placed was analyzed in order to determine if different patterns of exploration were evident among the three groups. Different exploration patterns would be expected given the information available from the map for each group. The comprehension group has the layout of the targets in front of them at all times, the production group has the environmental layout without the flags in front of them at all times, and the no-map condition has no symbolic medium with which to structure their search.

To investigate the patterns across the three groups, transition matrices for each condition were created. These matrices are found in Table 8 and are pictured graphically as weighted network maps in Figure 17 (note that the figures are not able to illustrate the directional nature between each flag location). It is important to keep in mind that the network maps are somewhat misleading for the comprehension group because it forces the flag locations to be correct, when obviously not all placements were in the correct location. It does, however, give a sense of the pattern of exploration the children were engaging in. In regards to the matrices, many cells are empty and it is therefore not possible to perform non-parametric statistics on these data. Tables (and figures) reveal several clear differences among the three conditions. For the comprehension group there is a clear pattern of exploration. Notice that the comprehension group has 5 cells that occur with a much higher frequency compared to the other transition cells. While the starting point may have varied somewhat across individuals, those in the comprehension condition and therefore with the flag layout available to them at all times, typically followed a similar sequence — from red to yellow, yellow to green, green to blue, blue to black, and black to white. By comparison, the other two groups show considerably less concentration in these cells, though the production group does show some concentration for three of these transitions (red to yellow, blue to black, and black to white). The no-map group's transition pattern is much less concentrated, but there is still some evidence of certain transitions being favored over others. Implications of these results are addressed further in the discussion.

Task duration. Using the video data, each participant's task duration (i.e. time taken to find or place flags) was calculated. This measure was then used in a 2 (sex) X 3 (condition) ANOVA. The only significant effect was a main effect for condition, $F(2,52) = 10.88$, $p < .001$, $\eta_p^2 = .29$. Post hoc tests with a Bonferroni adjustment to control for multiple comparisons indicated that those in the production group took significantly longer than both the comprehension and no-map groups. Means (SDs) for the three groups, respectively, were, 1,507.2 s (534.2 s), 950.2 s (280.2 s), and 1,072.6 s (266.0 s). This effect is illustrated in Figure 18.

Next I turn to the other observable behavioral strategies children engaged in while completing the two mapping tasks. Given the results on differences in task duration it is important to look at these strategies both as measured by total time engaged in a specific strategy as well as by examining proportion of the total time engaged in each strategy. Using both measures is informative of the raw time spent using specific strategies as well as how often strategies were used relative to the total task duration. In addition to looking at strategy use across the entire session, the strategies were also examined in relation to the sequence of flag and sticker placement. That is this analysis examined strategy patterns between the beginning of the task and placing the first flag or sticker, between placing the first and second flag or sticker, etc. To look at this, a repeated measures ANOVA is also reported for each strategy to see if there were any changes over time with strategies. Note that only the proportion of time spent on each strategy between flags is used as the dependent measure when looking at changes across the flag sequence. This was done because using the total strategy use time in this way would be confounded by the time spent between each flag and it would be unclear if differences were a result of a different pattern of strategy use or differences in time between each flag. Also note that the no-map group is not included in these analyses as they had no map with which to exhibit strategies.

Looking at the map. The first strategy discussed in regards to strategies directly related to interacting with the map is the time spent looking at the map. I first look at the total time spent looking followed by the proportion of total task duration spent looking at the map. Two 2 (sex) X 2 (condition) ANOVAs were used to examine group differences. With total looking time as the dependent measure, there were no significant main effects or interactions. A repeated measures ANOVA was then used to determine if there were any changes across the testing session in proportion of looking time at the map. The between-subjects variables were again sex and condition. The within-subjects variable had 6 levels, one for each flag. The results indicated a significant condition X flag sequence interaction, $F(5,170) = 8.16$ $p < .001$, $\eta_p^2 = .19$. As can be seen in Figure 19, this interaction results from the comprehension group looking at the map for a consistent proportion of time across the entire task whereas the production group starts out at a similar proportion of time, but decreases their map looking behavior as they go through the task. Subsumed under this interaction was a significant main effect for condition, $F(1,34) = 23.03$, $p < .001$, $\eta_p^2 = .40$ and a significant main effect of flag sequence, $F(5,170) = 5.68$, $p < .001$, $\eta_p^2 = .14$.

Map alignment. As with the looking time data, the time spent with the map aligned with the space was also looked at both as a total measure and as a proportion of the task duration. The

2 (sex) X 2 (condition) ANOVA with total time as the dependent measure revealed no significant effects. However, the main effect of sex approached significance, $F(1,34) = 3.57$, $p = .067$, $\eta_p^2 = .09$ in the direction of boys (M = 306 s, SD = 143 s) aligning the map more than girls (M = 228 s, SD = 110 s). Next a repeated measures ANOVA was run with sex and task as the between-subjects measures and the 6 flags as the within-subjects measures. This analysis revealed a main effect of sex, $F(1,34) = 5.00$, $p = .032$, $\eta_p^2 = .13$, showing that boys aligned the map for a greater proportion of time than did girls. Means (SDs) for boys and girls, respectively, were, .28 (.18) and .19 (.06). Figure 20 shows the effect of sex. There was also a significant effect of flag sequence $F(5,170) = 15.91$, $p < .001$, $\eta_p^2 = 32$. As can be seen in Figure 21 the proportion of time spent aligned was quite high for the first flag and then falls dramatically. The proportion then gradually goes up, showing increased use of the alignment strategy as the children go through the task.

Looking at the aligned map. While differences in both looking and aligning are informative, differences in looking at the map when it is aligned with the space may also be important. Therefore a new code was created for anytime map alignment overlapped with looking at the map. Total time and proportion of time that this occurred were once again used in two separate ANOVAs. For total looking time at the aligned map there were no significant effects. Although just as with map alignment duration there was a trend found with sex, $F(1,34) = 3.73$, $p = .062$, $\eta_p^2 = .10$. Again the trend was towards boys spending more time looking at the aligned map than girls, with Ms (SDs), respectively of 118 s (66 s) and 81 s (47 s).

The repeated measures ANOVA analyzing the aligned looking proportion across the six flags did result in a significant effect of flag sequence, $F(5,170) = 15.79$, $p < .001$, $\eta_p^2 = .32$, however the reason for this effect was because the period of time between starting and the first flag and sticker placement had a much higher proportion of alignment than between each of the other flag and sticker placements, with the remainder remaining relatively constant, as can be seen in Figure 22. Because this result was likely only due to the children starting with the map aligned, a more parsimonious 2 (sex) X 2 (condition) ANOVA was run to determine if there were any effects of condition. When this was run a much different pattern appears as compared to the total time. For this ANOVA there were significant main effects of both sex, $F(1,34) = 5.74$, $p = .022$, $\eta_p^2 = .14$, and condition, $F(1,34) = 6.32$, $p = .017$, $\eta_p^2 = .16$. Consistent with other effects already reported, boys (M = .11, SD = .08) exhibited this strategy more than girls (M = .06, SD = .03) and the comprehension group (M = .12, SD = .08) more than the production group (M = .06, SD = .04). Figures 23 and 24 illustrate the effects of sex and condition, respectively. There was no significant interaction found.

Turning the map. The next strategy analyzed was the number of map turns made by the children. These were turns made with the children's hands so that the orientation relative to the body changed. A repeated measures ANOVA was run with sex and condition as the between-subjects variables and flag sequence as the within-subjects variable. Despite differences in the amount and proportion of aligning the map, there were no significant differences in the number of turns of the map in relation to either sex or condition. However, there was a significant flag sequence effect, $F(5,170) = 3.71$, $p = .003$, $\eta_p^2 = .10$. Post hoc tests revealed that the number of turns for the first flag was significantly lower than all of the others, and that flag 6 had significantly more turns than all other flags with the exception of flag 5 (see Figure 25). There were no significant interactions.

Touching the map. The total duration and proportion of time spent touching the map (including pointing to locations or tracing routes on the map) was analyzed next. The same

ANOVAs that were run with the other duration codes were once again used for this code. As with turning the map there were no significant differences for map touching. For the repeated measures ANOVA looking at proportion of time touching the map across the six flags there was only a significant effect of flag sequence, $F(5,170) = 3.00$, $p = .013$, $\eta_p^2 = .08$. This is a small effect and results from the proportion of time touching being very low for the first flag as illustrated in Figure 26.

Pointing in space. The number of times each participant was observed pointing to something within the space was used as the dependent variable for the final repeated measures ANOVA with sex and condition as between-subject variables and flag sequence as the within-subjects variable. Pointing in space failed to be related to any grouping variables and there was no change over the six flags. See Table 5 for Ms and SDs for all variables including the frequencies of pointing in space. The range of frequencies for this strategy was 0 – 31, however, the individual who had a frequency of 31 was an outlier as the next highest frequency of pointing in space was 18.

Latent class analysis of strategy use. To explore the possibility that there were different strategy profiles, a latent class analysis was run using the strategies: looking at map, aligning map, touching map, turning map, and pointing in space. As the AIC and BIC values reported in Table 9 indicate, the two-class solution produced the best fit compared to the one- and three-class solutions. The two-class solution is also supported by the class probabilities for the two-class solution shown in Table 10. Graphs of the mean values for each strategy by latent class are shown in Figure 27. The first class, labeled low aligning, consisted of 31 children, whereas the second class, labeled high aligning, consisted of only 7 children. The classes were labeled low and high aligning because the major differences between the two classes appear to be the number of map turns and the proportion of time spent aligning the map. Because of the imbalance in the number of children in each class, further analyses were not run using these classes as grouping variables. However, a visual inspection of the data led to no apparent differences in class membership based on sex or condition. Implications for this analysis are addressed further in the discussion.

Relating All Measures Including Individual Differences in Spatial Ability

This next section of the results examines how task assignment is related to strategy use and how strategies are related to performance on the task itself as well as on measures of survey knowledge. In the process of determining these relationships I also look at how individual differences in spatial ability predict the various outcome variables discussed above.

Distortion index in relation to other variables. First I look at how strategies and spatial skills relate to performance on the placement task as measured by distortion index (DI). The first analysis run was a regression mirroring that done by Liben, Myers, and Christensen (2010) on similar map-use data in adults. The purpose of this analysis is to determine how spatial skills relate to performance and to see if sex is predictive of performance after accounting for other variables. To do this a hierarchical linear regression was run. At the first level, the four spatial skill measures (WLT, MRT, PFT, and HPT) were entered; on level two, the five map-use strategies (proportion looking at the map, proportion aligning the map, proportion touching the map, number of map turns, and number of points to things in the environment) were entered, and on the third and final level, sex was entered. Results indicated a significant effect of spatial skill on the first level with an $R^2 = .31$, $p = .013$. Within this level WLT was the only measure to predict DI above the shared variance with the other measures, $\beta = -.36$, $p = .027$. The negative value of β indicates that fewer WLT items within 10° of horizontal was associated with a higher

DI (i.e. worse performance). On the second level, strategies as a group predicted DI with an $R^2_{change} = .24$, $p = .025$. None of the individual strategies predicted above and beyond the shared variance, however the proportion of map alignment, looking, and touching were all approaching significance (see Table 11 for a full list of βs and significance levels). Sex, entered on the third level, did not contribute significantly after taking into account the other variables.

Given the results above regarding strategy use predicting performance and the ANOVA results already discussed that indicated differences in condition on DI, the goal of the next analysis is to determine the relationship between condition, strategies, and performance. Specifically, the goal was to address the hypothesis that effects of condition are mediated by the strategies the two conditions elicit as depicted in Figure 28. This was done by using the classic mediation technique as discussed by Baron and Kenny (1986). To do so required developing a composite strategy score. To create a single measure the frequency measures of map turns and pointing in the environment were dropped. Both of these measures were not related to any of the grouping variables and in the above regression there was no evidence that either explained unique variance in the model. Therefore the proportion of time aligning, looking at, and touching the map was used to create the composite measure. These three strategies at least approached significantly explaining unique variance in the regression above. The proportion of time that each child was engaged in at least one of these strategies was then calculated to get the combined proportion for strategy use.

Each step of the following mediation analysis controls for spatial ability. This serves to determine how spatial skills are related to the other variables as well as ensure that the results are robust enough to be exhibited above these individual difference measures (note that the analyses were also run without controlling for spatial ability, which resulted in the exact same pattern of results described below). The first step in testing the mediation model was to test if condition predicted DI. Condition did indeed predict significantly after controlling for spatial ability, β = -.47, p = .003, as would be expected based on the ANOVA above with the comprehension group outperforming (i.e. lower DI) the production group. The statistics for spatial ability predicting DI are the same as reported above. Second, a regression was run using the strategy score to predict DI, which was also significant, β = -.49, p = .002, indicating greater strategy use resulted in better performance (again, see above for the relationship between spatial skill and DI). The third regression determined that spatial skill predicted the proportion of strategy use, R^2 = .28, p = .024. The only spatial measure that significantly explained unique variance above the other spatial measures was the MRT, β = .36, p = .020. Next, after controlling for spatial skill, condition significantly predicted strategy use, β = .54, p = .001, indicating that being in the comprehension group is associated with greater strategy use.

Lastly, a regression was run using task to predict DI after controlling for both spatial skill and strategy use. Doing so eliminated the significant effect of condition, β = -.29, p = .091. A Sobel test (Sobel, 1982) indicated that the indirect effect of condition on DI as mediated by strategy use was significant, Sobel test statistic = -2.49, SE = 6.33, p = .012. Specifically, those in the comprehension group exhibit a greater proportion of strategy use, which predicts better performance on the task. This model is illustrated in Figure 28.

Spatial skills and strategies in relation to pointing and route to target. With the dependent measure as the mean error on the point to target task the same initial regression was run with spatial abilities on the first level, strategies on the second, and sex on the third level. None of these levels resulted in a significant change in R^2 and the final model was not significant. The R^2 values and significance levels for the three levels were as follows: level1, R^2

= .17, p = .167; level 2, R^2_{change} = .20, p = .142; and level 3, R^2_{change} = .02, p = .369. A second regression was run to determine if strategies would be predictive without controlling for spatial ability, however, this analysis also indicated that strategies were not related to accuracy in pointing to the target. This same pattern of results was true for route-to-target performance as well. The R^2 values and significance levels for the three levels in the route-to-target regression were as follows: level1, R^2 = .09, p = .507; level 2, R^2_{change} = .10, p = .640; and level 3, R^2_{change} = .09, p = .085. The fact that sex was approaching significance for the route-to-target task is not surprising given the significant main effect for sex in the ANOVA reported above. It is important to note that after controlling for spatial ability and strategies that the effect of sex was no longer significant.

DI predicting survey knowledge. Lastly, I looked to see if performance on the flag and sticker placement task would be predictive of performance on measures of survey knowledge. This was done by running two separate regressions with DI predicting pointing performance in the first and route-to-target distance in the second. One might expect that if a child did well on the placement task they would also do well on the measures of survey knowledge. This was not supported by the analyses as DI was not significantly related to either pointing or route-to-target performance.

Chapter 4

Discussion

The present study aimed to answer several important questions regarding children's use of maps and their acquisition of survey knowledge. Specifically, the following questions were asked: 1) Do children who complete a comprehension task perform differently from those who perform a production mapping task? 2) Are the processes (as measured by observable strategies) involved in completing comprehension and production mapping tasks different? 3) Do maps help children learn a survey perspective in a large naturalistic environment in comparison to exploration of the environment without the aid of a map? 4) Do individual differences in spatial ability as measured by paper-and-pencil laboratory tasks predict performance on large-scale map-use tasks?

This chapter first discusses the results from the present study along with implications for those results, followed by limitations of the study, then future directions that arise from the results and limitations, and finally some concluding remarks.

Summary and Discussion of Results

Task differences. The clear answer to the first two questions posed above is that comprehension and production mapping tasks induce a variety of differences in the map user. Children's performance on placement of the flags and stickers differed significantly between the two groups such that those completing the comprehension task were more accurate in their placement than were children in the production condition. This finding is consistent with other cognitive domains, such as language, that demonstrate comprehension skills prior to production skills (e.g. Goldin-Meadow, Seligman, & Gelman, 1976). Comprehension abilities have also been found to precede production abilities when children are asked to represent temporal sequences spatially (Koerber & Sodian, 2008). In the present study it was found to be easier for the children to read information from a map and put it into practice than it was for them to use information from the real world to alter a map of the space. This is contrary to tacit assumptions in the current map-use literature, which does not address potential differences in outcomes when completing comprehension and production mapping tasks. This is the first data to directly compare the two tasks using maps as opposed to a different symbolic medium. The findings have immediate implications for the way in which researchers study map use.

Some may argue that the comprehension task used here also requires an element of production because the participants must perform an action based on the information on the map. However, the definition of production here involves producing something in relation to the symbolic medium of the map and not the production of any behavior or response. This is surely consistent with language literature, as children must produce some action to indicate they can comprehend utterances, however, they are slower to produce similar utterances in the symbolic medium of language. Therefore, the distinction made between comprehension and production tasks in this study is supported by work done in other cognitive domains.

In addition to differences between map conditions in raw performance, there were differences in task duration and in the distance traveled while completing the task. The comprehension group was more efficient in completing the task both in terms of time and distance traveled. This is not surprising given that the comprehension group had the layout of all of the flags at their disposal on the map. This ability to consult the map in order to determine the nearest locations for the next flag placement likely lead to more route planning. Evidence that the comprehension group was engaging in more planning is found in the data from the time these children spent looking at the map. While total time did not differ between the groups, the comprehension group spent a greater *proportion* of time looking at the map, which means that they spent less time exploring without the aid of the map, thus suggesting their time was used more in making and executing a plan. Their more frequent consultation of the map likely led to better route planning and resulted in more efficient routes through the space to place the flags. The fact that the comprehension group was able to complete the task more quickly and in a shorter average distance suggests further that proficiency in comprehending how to use a map arises earlier than producing symbolic representations of space and perhaps that children's map education may benefit from a stronger concentration on production of map symbols.

These data taken together not only show that children perform differently when completing comprehension and production mapping tasks, but that the way in which the environment is experienced also differs. Completion of the production task resulted in greater exploration of the environment, whereas completion of the comprehension task elicited a greater proportion of time using the map. This finding can help researchers when choosing a mapping task to use for a particular study. If a task is desired that would encourage greater environmental interaction, a production task would likely be the better choice. However, if researchers are interested in more regular engagement with the map, a comprehension task would be more desirable. These findings also suggest that mapping devices may need to engage the user differently depending on the goal of the user and that a variety of experiences may be beneficial to environmental learning. Given the range of differences in the experiences between the two tasks it may be limiting to have only one type of interaction with a space. This is relevant for the educational domain as children may benefit from programs that provide them with a variety of map related activities. However, as mentioned above, it may also be that heavier focus should be placed on production tasks.

Strategy use. The most important finding regarding strategy use and individual differences came from the mediation analysis. This analysis demonstrated that the effects of task on children's performance are fully mediated through strategy use. Specifically, assignment to the comprehension condition led to greater use of strategies compared to the production condition and this increased strategy use was related to better performance. Therefore, as was predicted, the tasks elicited different behaviors from the children. By controlling for individual differences in spatial ability, it is evident that the task effect is robust in influencing the strategies spontaneously used by the children.

This finding in particular has serious implications for the study of map use. The evidence in this study suggests that it is not enough to simply choose any mapping task to study the abilities of children. The interpretation of whether a child does or does not possess the ability to use a map could hinge greatly on the task chosen. In addition, given the strategy evidence, it is unlikely that the two kinds of tasks are relying on the same cognitive processes. The comprehension group relies more on the map which is suggestive that they are more engaged in planning their routes through the environment to reach the desired locations. In relying significantly less on the map between flags, the production group may be taxing their visuospatial working memory. If one is not attending to the map regularly, then it would be necessary to keep one's location on the map in working memory instead of off loading information about location onto the external representation of the map. While this study cannot pinpoint the origins of the difference in strategy use, it is still important to point out that there *is* a difference because of the implications it has for the cognitive processes the children engage in for each task.

In addition to more clearly defining how differences in task demands can lead to better performance, the regressions run in the mediation analysis also demonstrate the importance of individual differences in spatial ability. The spatial ability measures were able to account for significant variance in both strategy use (children higher in spatial ability use the strategies a greater proportion of the time) and performance (children higher in spatial ability perform better on the placement task). This is consistent with previous literature that has shown that spatial abilities predict strategies and performance (e.g. Liben & Myers, submitted; Liben, Myers, & Christensen, 2010) and provides further support that paper-and-pencil measures of spatial ability can indeed predict how one will do on a large-scale navigation task, at least on the tasks investigated in this study. The influence of spatial skills on these outcome measures also suggests that between condition variability is not the only thing that accounts for differences in strategy use and performance. Clearly, there is variability within groups as well. This can partially be explained by basic spatial abilities. The significance of this lies in the fact that not all those in the comprehension group exhibited a greater proportion of strategy use. While there were clear group mean differences, it is also necessary to discover why individuals vary in both strategy and performance regardless of the condition assignment.

This study also examined the possibility that different strategy profiles were exhibited by children who were participating in these mapping tasks. A latent class analysis was able to identify two distinct groups of strategy patterns with one group associated with a high rate of aligning and turning the map and the other group associated with low rates of aligning and turning the map. Unfortunately, with the present sample, the distribution of these two classes was too imbalanced to attempt to run any further analyses to see what might be related to the patterns exhibited. There were, however, no clear identifying variables related to these classes with the seven individuals in the high aligning group relatively evenly split across sex and condition. It would be interesting to see whether a larger sample would provide evidence that these different strategy groups predict performance on other measures. However, the use of latent class analysis for this purpose could prove to be heavy handed. Considering there were just two classes identified and the classes only differentiated by strategies that involve aligning the map, it may be sufficient to simply look at alignment strategies in relation to other variables. In the present data the raw proportion of strategy use was sufficient for establishing a relationship with performance. While it was worth determining the classes that could be extracted from these data, the latent class analysis is unlikely to be a fruitful pursuit with future data of this kind. Instead it is likely more informative to use the raw strategy data.

The strategy data from this study also support the importance of aligning the map as a strategy to be successful at tasks such as this one, which replicates previous data (Liben & Myers, submitted; Liben, Myers, Kastens, 2008). Data from other authors has shown that when a map is unaligned with the space, users often walk in the wrong direction (Levine, 1982; Levine, Marchon, & Hanley, 1984). Data from our own lab has provided support that aligning the map has a causal influence on performance in tasks involving determining location and facing direction on a map (Christensen & Liben, 2010). These data are as yet unpublished other than a conference presentation, but show that when the map is aligned for participants and they are prompted to keep it aligned throughout the task they perform much better than when they are not given the map aligned. Of particular interest in this alignment study is the finding that simply telling participants that aligning the map with the space might help leads to better performance, even if they don’t actually physically align the map with the space.

Collectively, the data on alignment is applicable outside the realm of paper map use. As the popularity of electronic maps and automated directions increases, in order for the individual to really understand where he or she is, it is important for alignment to be a primary focus in the designing of GPS systems. Of course these devices try to limit the burden on the user, so interfaces would have to be designed in such a way that user attention is focused to emphasize spatial learning, but does not require too much time on the part of the user. Perhaps indicating how the map needs to be turned to be aligned, but requiring the user to manipulate the map into the correct position on the screen could be a way to achieve both goals, though this is obviously not a good idea for in-car navigation systems. Finding ways to make electronic mapping devices user-friendly as well as supportive of spatial learning is the goal of a variety of lines of work (e.g., Klippel, Dewey, Knauff, Richter, Montello, Freksa, & Loeliger, 2004; Lee, Klippel, & Tappe, 2003), and this particular aspect of map use could be a beneficial point of focus for researchers involved in this work.

Strategies in relation to time. There were several significant results that came out of the repeated measures analyses looking at strategy use across the sequence of six flags. The first was an interaction between flag and condition on the proportion of time spent looking at the map. Children in the comprehension condition were relatively stable across all six flag and sticker placements whereas the production group showed a consistent decline across the six placements. This supports the hypothesis that the children in the comprehension condition were actually planning their route from flag to flag. Children in the production condition, on the other hand, would not have been able to do such planning. If they did not recognize the utility of keeping constant track of their location on the map they likely would have waned in using it over the course of the study. Alternatively, they may have lost track of where they were and given up on keeping track of their position on the map. What is less obvious is why they initially looked at the map the same proportion of time as the comprehension group. It could be because they recognized that there was some usefulness of the map in completing the task initially, but ultimately decided that it is only really needed when a flag is found. Or it may be that they were just attracted to the novelty of the map initially, but once they had studied it that novelty wore off. Whatever the reason for the initial looking response it is clear that the comprehension group exhibits greater use of the map over the course of the mapping activity.

The effects of flag sequence on the proportion of time spent aligning the map and looking at the aligned map are much more easily explained. The children began in a particular facing direction and were given the map in such a way that it was aligned with the space. All but a few of the children began by walking straight ahead towards the closest flag location, which was the red flag. As a result of this starting orientation and the dominant response of children to begin by simply walking straight ahead, the first flag showed a large spike in the proportion of time aligning and looking at the aligned map.

A similar argument can be made to partially explain the flag effect on number of map turns. Because the children were initially shown where they were standing (at the “X” on the map) and because the map was aligned (though they were not told that it was aligned with the space), there was little need to turn the map, even for those that later found turning the map helped them. What is not clear is why the frequency of map turns would spike when working on the final flag placement when it was remarkably stable for positions 2-5. In addition, the proportion of time aligning the map did not spike in this same way, so it was not that the children were suddenly better at keeping the map aligned on the last location. It could be that the children started to recognize by the sixth flag that trying to align the map with the space could be helpful.

This is not likely though because there were only three children who turned the map for flag six that did not turn the map for flag five. So it appears that for some reason those that were turning the map simply exhibited this strategy to a greater degree for the last location. The present data make it difficult to explain why this occurred.

Sex differences and differences in individual spatial abilities. For the most part the current data support and replicate findings from previous studies regarding sex differences. Sex was found to be a significant predictor of the map alignment strategy consistent with Liben and Myers (submitted). Consistent with some of the adult literature there were no sex differences on performance on the placement task once spatial ability had been controlled for (Liben, Myers, & Christensen, 2010), but there was a main effect of sex in the ANOVA on DI when spatial ability was not controlled for such that boys were more accurate than girls. This main effect is consistent with the data from the Liben and Myers study. The interpretation of the effect of sex no longer reaching significance after controlling for spatial ability is the same as that made by Liben et al, that sex is not as descriptive or as important as other individual difference measures. A notable exception is data from Liben, Kastens, and Christensen (2011) that found a sex difference on a geology task despite recruiting men and women in such a way that water level performance was roughly equal. The finding of a sex effect in the Liben et al. (2011) study when there was none in this and other studies could be attributed to differences in the task under investigation, or it could be because Liben et al. (2011) only used the WLT to control for spatial ability whereas the other studies used a broader range of spatial skill measures that cover Linn and Petersen's (1985) three categories of spatial skill. This possibility was suggested in the initial Liben et al. (2011) paper and the present data provides some support for the speculation.

Spatial skill measures were positively related to performance as would be expected. Better spatial skills also predicted an increase in the total proportion of strategy use. The relationship of spatial skills with strategy use replicates previous work that has shown that those with better spatial skills are more likely to align the map (Liben & Myers, submitted). These data also extend those previous findings by using a continuous measure of strategy use and a combination of strategies beyond map alignment.

Spatial skills did not predict children's performance on either measure of survey knowledge. The lack of findings in regard to survey knowledge acquisition is discussed below with other results regarding survey knowledge.

Survey knowledge acquisition. A finding which was not consistent with the initial hypotheses is that using a map within the space did not lead to better survey knowledge when compared to searching for the flags without a map. Given the previous research with both children and adults it was expected that maps would be beneficial to implicitly learning the survey perspective. There are several reasons why this hypothesis was not supported.

It is unlikely that the tasks were too difficult for the children considering the Rayleigh V-test and visual inspection of the rose plots in Figure 12 suggest that as a whole the children had a general idea of where the target was in relation to the four pointing locations. Additionally, the route-to-target task was sensitive enough to identify a significant effect of sex. However, the goal directed nature of the mapping tasks may have interfered with the ability to gain an advantage in survey knowledge over the no-map condition. As mentioned earlier, Rossano and Reardon (1999) found that survey knowledge is harder to obtain when focusing on a target location. Perhaps a similar difficulty is present in the current data when children are focusing on the goal of placing their flags or stickers accurately.

Another possibility is that the children simply spent too much time exploring the environment. As noted by Thorndyke and Hayes-Roth (1982) there is an initial influence of map use on the acquisition of survey knowledge, but prolonged experience in the environment can also lead to accurate survey knowledge. There is no clear evidence with children in this age range indicating what is a sufficient amount of time to spend in an environment to acquire the survey perspective.

Related to the previous point, there were also group differences in the amount of time spent and the distance traveled while completing the flag and sticker placement task. Given the naturalistic nature of this study, children were free to explore the space however they wanted and to take essentially as much time as they needed. Perhaps these differences are masking any effects on survey knowledge. It is a possibility that if the task duration and distance traveled could somehow be kept constant across all groups there would be some influence of the task assignment on survey knowledge. However, the present data cannot speak directly to such a possibility.

Yet another reason for the lack of condition effects on survey knowledge could have to do with the characteristics of the testing environment. While the space is relatively complex in many ways, it is in other ways an ordered space. Topographically the space slopes downward from north to south and the space is broken into several sections separated by stairs. Also, while the space has some relatively symmetrical qualities, the construction that was underway during the testing of all children made the space much less symmetrical than it would be without the construction. These characteristics of the space may have made it easier to remember where the penny was by noting it was away from the construction and was on the highest section, or at the top of the slope.

Specific to the route-to-target task, it is possible that children could rely on route knowledge more than was initially intended. While none of the children had traveled from the particular start location used for the task to the penny, children could have found their way to a familiar path they had used to travel to the area with the penny during the flag and sticker placement task. Without asking children what their strategies were to get back to the penny it is difficult to know how likely this possibility is.

Also of noteworthiness regarding the acquisition of survey knowledge was that performance on the placement task did not predict how well children would do on the measures of survey knowledge. One would expect that if an individual has a good sense of where they are in the space (as indicated by performance on the placement task) then they would also be better able to relate points in the space. However, this was not the case in these data. A possible explanation is that being good at keeping track of current location using a symbolic medium does not translate into being better able to keep multiple locations in the mind simultaneously.

Adding to the puzzle is the lack of relationship between spatial skill and survey knowledge as mentioned above. It is surprising that none of the variables measured in the present study were related to performance on the measures of survey knowledge with the exception of the effect of sex on the route-to-target task. In fact, performance on the pointing task and route-to-target task are not significantly correlated with one another, $R(56) = .19$, $p = .076$, though this is a trend towards the measures being positively correlated. This may suggest that the two measures assess different aspects of survey knowledge (or that children could have relied on strategies other than survey knowledge in the route-to-target task), but it still does not provide an answer as to why there were no significant relationships between other variables of interest and these survey measures.

Effect of sidewalk construction. As stated previously, there was construction taking place within the testing area for a subset of the children. Fortunately, this construction occurred for roughly equal numbers in each condition and did not interact with any other grouping variables. What was surprising was that the presence of this extra construction had a direct effect on performance on the flag and sticker placement task. Those who completed the task with the construction had significantly lower DIs, indicating better accuracy, than those tested without the additional construction. One possibility for this effect is that the construction provided the most distinct and salient landmark in the space as it created an obstacle that needed to be walked around. It is unlikely that the elimination of that area as a potential flag placement was the cause of the effect. The area was relatively small in relation to the overall environment and, as can be seen from the composite maps in Figure 8, there were only two flags placed in this area by children in the comprehension condition when the construction was not in the way of placing flags there. Whatever the reason for the effect, it likely did not impact the results of the other analyses.

Findings support broader constructivist theoretical framework. The present results speak to issues beyond children's map use. As laid out in the introduction a theoretical background for this work comes from various constructivist researchers and philosophers. The current data provide strong evidence that experience does matter and that experiencing the same environment can lead to very different outcomes if the quality of that experience is manipulated. A simple manipulation in the goal of the participants in the present study led to a cascading effect first on their behavior and ultimately on how well they were able to place the flags and stickers in the appropriate locations.

The strategy data are particularly relevant regarding this broader theoretical framing of the questions. These data illustrate that it was not just the goal that differed between the two tasks, but that the way the children interact with the environment varies on a number of different measures. The mediation analysis suggests that it is this difference in interaction that is related to differences in performance. One could argue that this indicates a different sense of reality as was described by Bruner (1991) and that the differences seen between the tasks are consistent with the Piagetian notion that how we interact with the environment is an important factor in our construction of reality. Despite this support, one must be cautious when making strong claims in this vein with the current data because the lack of differences in survey knowledge qualifies the other results. Given a main hypothesis of this study was that map use would lead to better survey knowledge compared to a no-map condition, it is difficult to make strong claims about the influence of maps on knowledge acquisition from these data. So while the data is important regarding the type of interaction with the map and space, it does not provide support to the extant literature suggesting that maps are a tool for helping us learn the survey perspective of a given area. This is somewhat inconsistent with the extant literature and warrants further exploration as described below.

Limitations

Despite several important and illuminating findings from the present study, there are some limitations that should be addressed. First of all, the naturalistic nature of the task and the setting, while making it possible to argue differences elicited by comprehension and production tasks are relevant for real world behavior, limited the amount of control over several factors that may prove to be important in future work. The two mapping tasks used in this study differ in many respects that may have contributed to the differences seen. It is also important to consider the amount of information available to the participant as well as the amount of time and distance it took for the respective groups to complete the task. Both provide a means for planning a search strategy through the environment, but only the comprehension task provides the locations to help structure the search strategy with optimum efficiency for the flag configuration. The present data cannot speak to which of these, or other, differences are driving the results found in this study.

The lack of control over the time spent and distance traveled in the space is also a notable limitation. The differences seen in amount of time in the space could be a potential reason there were no group differences (other than a gender difference on the route task) on the measures of survey knowledge. There may have been an initial benefit to using the map, but the lengthy amount of time spent in the space may have washed out that initial benefit.

A further limitation of this study was the lack of control over the type of location and the order in which the locations were visited. Because of this lack of control it was decided that characteristics of the space would not be explored with the present data. One relevant question that remains unanswered by this study is what role the environment and specifically the characteristics of the target locations play in participant performance. There are various space syntax measures (Klippel, Hirtle, & Davies, 2010; Klippel & Winter, 2005; Li & Klippel, 2010) that could give a better idea of when localization tasks are harder or easier. Careful control over target locations could help show how these environmental factors interact with group and participant variables.

In addition to precluding the use of space syntax measures, the lack of control regarding order of the locations visited prevented analyzing performance based on flag location. The repeated measures analyses reported in this study involve the sequence of flag and sticker placements, not differences between the specific locations. Trying to determine if the red flag was harder than the green flag is too confounded by the lack of control over order to make any claims regarding performance at specific flag locations. This is especially true given that there were obvious patterns within groups when looking at the transition matrices and network maps (Table 8 and Figure 17). In sum, using space syntax measures to carefully select locations and then controlling for the order the locations are visited would make it possible to look at how the environment influences performance in relation to the variables used here.

A measure not included in the current study that would have been beneficial would be a measure of visuospatial working memory. Given the argument made that the comprehension group is doing more planning and the production group must hold onto the information from the map longer because they are using the map less, it would make sense that visuospatial memory would play a significant role in who is able to perform well. This may be especially true for the production group. It may not matter as much in the comprehension group because these children rely more heavily on the map and can therefore offload the cognitive requirements of keeping track of where they are in the space onto the symbolic medium of the map. Finding that visuospatial working memory ability is related to production performance, but not comprehension performance, would further the claim that the differences between the tasks lie in the process of completing them and not just in how well children place their flags or stickers.

A further limitation is in the methods for collecting strategy data. While the current study is unique in that it was able to keep a continuously running account of strategy use including eye gaze, the equipment used did have some limitations. The POV camera used here was sufficient for recording general gaze, however, a mobile eye-tracking device could provide a much richer set of data in regards to where the children were looking. Being able to analyze where the children are looking on the map and coupling that with their location and where they are heading could provide more definitive support of the notion that children in the comprehension condition were doing more planning than the children in the production condition. This could be done without having to ask the child to articulate the strategy they are using thus obviating any concern about influencing how well they perform. Think-aloud protocols with this kind of data have been shown to influence performance, so the potential ramifications of such protocols should be considered (Kastens & Liben, 2007).

These limitations and some of the open questions discussed above lead to a series of potential future directions for this line of work. These possibilities are discussed next.

Future Directions

Many of the limitations in this study originate from its nature and design, however, its nature and design are some of its most important contributions. The naturalistic setting provides evidence that the behaviors and phenomena observed are relevant for map use in the real world. It also draws into question whether children can use a map to improve their survey knowledge when the environment is not simple and tightly controlled. Now that this foundation has been laid and difficulties have been identified, future studies can work to fine-tune the methods and avoid some of the inherent difficulties.

While demonstrating definitively for the first time using a direct comparison that production and comprehension tasks result in a variety of performance and strategy differences, the present study leaves open the question of what it is specifically about the tasks that create such differences. Now that the effect has been established in a naturalistic setting, showing that this is likely something that is found in real experience and not just in small-scale carefully controlled laboratory settings, it would be beneficial to now look at the phenomena in a much more controlled fashion. Some manipulations that may help shed light on this issue would be to only give the comprehension group one location to work on at a time instead of giving them a map with all of the locations laid out before them. There could also be more salient landmark cues indicated on the map that may elicit individuals working on a production task to keep better track of where they are at all times. The current layout and map had very few distinct landmarks that could be used in this way.

It would also be useful to try to manipulate the strategies the children use. The present study made no suggestions to the children about what strategies may or may not be useful. Prompts could also be given along the way to have the children show the experimenter where they are on the map or the experimenter could let the children know where they are on the map to cue them to the fact that keeping track of location continuously is beneficial for the task. Alternatively, given that adults merely need the suggestion of aligning the map to improve performance, perhaps the same would be true for children, although at least some minimal training may be needed for children to be able to effectively employ some of the strategies such as aligning the map with the space. Exploring manipulations such as these can help give a better idea of what is truly important about the behaviors the tasks elicit. It can also bolster the claim that the process or strategies engaged in during the task are what really influence performance on placement accuracy.

The lack of effects on survey knowledge should also be explored further. To determine whether too much time spent in the environment led to the lack of differences, a shorter task could be developed and the initial walkthrough could be taken out of the design. If children only have to work on one or two locations and can finish in a fraction of the time the present design took, then perhaps those using a map would show better survey knowledge acquisition. It is more difficult to control how far the participants travel when doing the task. Perhaps in order for this to be accomplished a simpler environment would be needed. However, this too could lead to a lack of differences in survey knowledge as presumably a simpler environment would require less time to learn the survey perspective through direct experience. An alternative would be to give the participants a limit on how far they are allowed to travel to complete the task, though this could have other effects on their behavior that would have to be considered, such as potentially causing those in the production group to be more conscientious of planning their route.

There is also a need to expand this line of work to incorporate automated and handheld electronic mapping devices. Although I defend the need for understanding how people use and learn from paper maps, it is clear that mobile mapping devices are going to have a continued and increasing influence on how people navigate. Understanding how we learn from and interact with paper maps will not only help us learn more about how we interpret and understand our surroundings, but will also inform the design and production of effective mobile mapping devices. Clearly, more comparison studies are needed to determine the ways in which the two modes of map use differ and how they are related.

Lastly, the age range of participants in this line of work should be expanded. Work using similar tasks to the ones in this study shows that participant performance improves with age. This is evidenced by the fact that adults find the space used in these studies for children far too easy. (Liben, n.d.). However, there is no work which looks at the developmental trajectory of strategy use. It is not clear whether adults in a similar task would show an increase in the proportion of strategies used. This is a tricky problem to address because care would need to be taken to ensure that the spaces used for children and adults were proportionally difficult and similar in qualities such as landmark cues. If done properly a study comparing children and adults could suggest common solutions to map use struggles.

In addition to looking at adults, work should also be done to investigate these skills in younger children. Perhaps younger children in the same space used here would show wider variability on the measures of survey knowledge. It might be the case with younger children that having the map available while completing the tasks would lead to better acquisition of the survey perspective.

Conclusions

The present study definitively shows in a direct comparison that comprehension and production mapping tasks result in differences of child performance on a variety of measures. The results suggest that these differences involve at a minimum the behavioral patterns elicited by the tasks (and potentially the cognitive processes involved in completing them), as well as how accurately children are able to mark locations in the two tasks. Further research is needed to decipher the key components of each task that result in the different patterns of behavior and performance, but the present study shows that this occurs in a naturalistic setting and is therefore worth pursuing. Importantly, the differences found here make it clear that careful consideration is needed when selecting mapping tasks to use for the investigation of map abilities and the strategies and behaviors elicited when using a map.

This study also supports previous data in suggesting that laboratory paper-and-pencil measures of spatial ability are indeed useful for predicting performance on map related tasks. However, they were not predictive of performance on measures of survey knowledge. The lack of any relationship between variables used here and the measures of survey knowledge warrants further investigation.

More broadly, these data suggest the need for further investigation of and a stronger emphasis on spatial education, specifically map education. Despite many claims of core map-use competencies in very early childhood by some researchers, it is clear from this and other studies that even children approaching adolescence can struggle with using maps to either find locations in the environment or to symbolically represent locations on a map. Results from the present study suggest that one fruitful target of education may be the strategies used to complete mapping tasks. Because of this, it is important for future work to attempt to uncover the process by which these strategies work to achieve improvements in map-use performance. Doing so may suggest ways in which the strategies may be taught or implemented that can create the maximum impact on children's understanding of how to use a map appropriately in different contexts. A better understanding of the processes underlying map use can also be applied to the ever expanding market of electronic mapping devices and applications. Applying this knowledge to the educational and electronic mapping domain can help individuals remain or become more spatially competent while still utilizing technologies that ease the every day burden of finding one's way around the environment. We need to ensure that as Wood and Fels (1992) stated, maps continue to "give us, *reality*, a reality that exceeds our vision, our reach, the span of our days, a reality we achieve no other way" (pp. 4). Though the medium through which we work with maps may change the tools and education available must be able to realize these benefits of maps.

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APPENDIX : Tables and Figures

Table 1. Definitions of terms and tasks

Term	Definition
Implicit Knowledge	Knowledge that is not attained because of explicit instruction to do so. Similar to implicit memory as defined by Hagen and Stanovich (1977). In the present context the children are asked to determine locations either from the map to the real world or vice versa, but they are not explicitly told to learn the configurational layout of the environment in order to perform measures of survey knowledge.
Survey/Configurational Knowledge	The ability to mentally represent the absolute relationships between various points in an environment. This includes the ability to determine heading direction and distance from one point to another.
Production Tasks	Defined by Liben (1997) as tasks that involve producing or altering a map. This may be creating a sketch map, or it may be adding symbols or modifying a base map in some way based on what is observed in the environment. In the present context children were asked to find flags in the environment and then place color-coded stickers on a map to indicate the locations of those flags.
Comprehension Tasks	Defined by Liben (1997) as tasks that involve acting in some way in the environment based on information given in a map. This can include following a route indicated on a map. In the present context children were given a map that had color-coded stickers to indicate where flags should be placed in the environment. The children needed to place the flags in the correct location as indicated by the map.
Point-to-Target Task	One of the two measures of survey knowledge used in this task. Used by many other researchers as a measure of survey knowledge, pointing to a target requires a participant to accurately determine the straight line path for a target that is out of sight. A distance estimate was not used in the current study because pilot testing indicated it was too difficult for children this age in this environment.
Route-to-Target Task	The route task was a second measure of survey knowledge that required participants to take the shortest route they could think of to get back to the target. This required survey knowledge because participants had not traveled directly between the starting point for this task and the target. Therefore participants needed to rely on their knowledge of the configuration of the space in order to be efficient in returning to the target.
Water Level Task (WLT)	The water level task is a Piagetian task that asks children to draw what the water surface would look like in a series of tilted bottles. This falls under the spatial perception category of Linn and Petersen’s (1985) classification of spatial tasks.
Mental Rotation Task (MRT)	The mental rotation task requires children to mentally manipulate a series of figures to determine which items can be made to look exactly like a target item by only rotating the figures. This falls under the mental rotation category of Linn and Petersen’s (1985) classification of spatial tasks.
Hidden Figures (HPT)	The hidden figures tasks consists of a series of line drawings in which children need to identify a specific shape that is embedded within each. This falls under the spatial visualization category of Linn and Petersen’s (1985) classification of spatial tasks.

Paper Folding Task (PFT)	The paper folding task involves imagining how a piece of paper would look after it has gone through a series of folds prior to having a hole punched through the folded layers. This falls under the spatial visualization category of Linn and Petersen's (1985) classification of spatial tasks.

Table 2. Distribution of participants by age and gender across conditions

	9 year olds			10 year olds		
	Production	Comprehension	No-map	Production	Comprehension	No-map
Boys	5	4	4	5	6	6
Girls	4	4	5	5	5	5

Table 3. Kappa values for strategy codes.

Code	Kappa
Alignment	.77
Looking	.89
Touching	.88
Turns	.51
Pointing	.69

Table 4. Summary of main findings (note that this table only summarizes main effects of grouping variables and does not summarize data from regressions relating the outcome variables)

DV	Condition	Sex
Distortion Index	Comprehension < Production	Boys < Girls (not significant in regression controlling for spatial ability)
Scale	Production contracted layout more than comprehension	Girls contracted layout more than boys
Theta	Trend towards production rotating array more than comprehension	No significant difference
Pointing Error	No significant difference	No significant difference
Route-to-Target Distance	No significant difference	Boys took shorter routes back to the target than girls
Distance Traveled During Mapping Task	Comprehension < Production, No-Map	No significant difference
Flag Order	Comprehension appears to search more orderly than production and no-map	No comparison made
Task Duration	Production > Comprehension, No-Map	No significant difference
Looking at Map Duration	No significant differences	No significant difference
Looking at Map Proportion	Interaction with flag sequence: comprehension stable, production decreases across flags	No significant difference
Map Alignment Duration	No significant difference	Approaching significance with boys > girls
Map Alignment Proportion	No significant difference	Boys > Girls
Looking at Aligned Map Duration	No significant difference	Approaching significance with boys > girls

Looking at Aligned Map Proportion	Comprehension > Production	Boys > Girls
Turning the Map	No significant difference	No significant difference
Touching the Map	No significant difference	No significant difference
Pointing in Space	No significant difference	No significant difference

Table 5. Means (SDs) for all variables by sex and condition

Variable	Comprehension	Production	No-map	Boys	Girls	Total
Distortion Index	31.8 (26.5)	52.2 (30.5)	NA	32.9 (27.0)	52.2 (30.6)	42.0 (30.0)
Scale	0.87 (0.22)	0.70 (0.28)	NA	0.86 (0.24)	0.70 (0.28)	0.78 (0.27)
Theta (°)	9.5 (15.3)	19.5 (88.2)	NA	11.0 (59.9)	18.4 (67.0)	14.5 (62.6)
Task Duration (s)	950 (280)	1507 (534)	1072 (266)	1162 (382)	1188 (506)	1175 (442)
Placement Route Distance (m)	763 (226)	1126 (242)	979 (297)	980 (304)	931 (286)	956 (294)
Pointing Error (°)	38.4 (24.1)	39.2 (26.5)	43.9 (32.7)	34.9 (23.4)	46.6 (31.0)	40.5 (27.7)
Route to Target Distance (m)	315 (128)	302 (76)	300 (86)	276 (77)	336 (108)	306 (98)
WLT within 10°	2.6 (2.1)	3.0 (1.9)	2.2 (1.8)	2.9 (2.0)	2.3 (1.8)	2.6 (1.9)
MRT Score	11.0 (3.1)	8.3 (5.2)	8.8 (5.4)	10.2 (4.7)	8.5 (4.8)	9.3 (4.8)
PFT Score	3.5 (2.7)	5.2 (3.1)	5.4 (4.8)	5.2 (4.3)	4.3 (3.0)	4.7 (3.7)
HPT Score	4.8 (2.9)	6.2 (2.2)	4.5 (2.5)	5.5 (2.5)	4.8 (2.6)	5.2 (2.6)
Proportion Looking at Map	,41 (.06)	.25 (.09)	NA	.33 (.12)	.34 (.11)	.33 (.11)
Proportion Aligning Map	.26 (.18)	.22 (.10)	NA	.28 (.18)	.19 (.06)	.24 (.14)

Proportion Touching Map	.11 (.14)	.08 (.12)	NA	.12 (.15)	.06 (.09)	.09 (.13)
Map Turns	4.6 (7.3)	4.4 (8.3)	NA	5.8 (8.2)	3.2 (7.1)	4.5 (7.7)
Points to Space	5.1 (5.7)	7.4 (8.2)	NA	6.8 (7.9)	5.6 (6.1)	6.3 (7.0)
Duration Looking at Map (s)	403 (155)	390 (236)	NA	369 (165)	427 (228)	396 (197)
Duration Aligning Map (s)	237 (129)	302 (131)	NA	306 (143)	228 (110)	269 (132)
Duration Touching Map (s)	118 (156)	137 (265)	NA	166 (271)	86 (122)	128 (215)

Table 6. Distribution of additional sidewalk construction

Comprehension		Production		No-map	
No	Yes	No	Yes	No	Yes
8	11	8	11	7	13

Table 7. Distribution of participants with correct pointing locations within 45° and 90°.

Number Correct	Number of Participants	
	45°	90°
0	4	0
1	8	5
2	11	5
3	16	14
4	19	34

Table 8.1. Comprehension flag order transition matrix

From \ To	Red	Green	Blue	Black	White	Yellow
Red	—	3	0	0	0	15
Green	0	—	17	0	1	1
Blue	0	1	—	17	1	0
Black	1	0	1	—	15	1
White	1	0	0	1	—	2
Yellow	1	12	1	1	2	—

Table 8.2. Production flag order transition matrix

From \ To	Red	Green	Blue	Black	White	Yellow
Red	—	3	4	0	0	12
Green	1	—	5	2	1	2
Blue	0	5	—	12	1	1
Black	0	1	2	—	12	1
White	2	4	2	3	—	3
Yellow	1	4	4	2	5	—

Table 8.3. No-map flag order transition matrix

From \ To	Red	Green	Blue	Black	White	Yellow
Red	—	1	1	0	0	16
Green	1	—	4	2	6	0
Blue	0	7	—	8	0	0
Black	0	0	9	—	8	0
White	0	2	2	10	—	4
Yellow	2	7	4	0	6	—

Table 9. Fit statistics for one-, two-, and three-class solutions for strategy profiles. The three-class solution was not calculated because the model crashed due to a non-positive definite error.

Classes	AIC	BIC
1	391.0	407.4
2	366.4	392.6
3	N/A	N/A

Table 10. Strategy latent class probabilities.

Class	Probability
Low aligning	1.00
High aligning	0.99

Table 11. β weights for hierarchical regression on DI.

	β	*p*-value
Level 1		
WLT	-.36	.027
MR	-.22	.136
PF	.06	.720
HP	-.26	.101
Level 2		
Looking	-.31	.060
Aligning	-.28	.073
Touching	-.28	.076
Turns	.10	.496
Points	.17	.299
Level 3		
Sex	-.18	.222

Figure 1. Diagram from Liben (1997) depicting the four methods for studying map use.

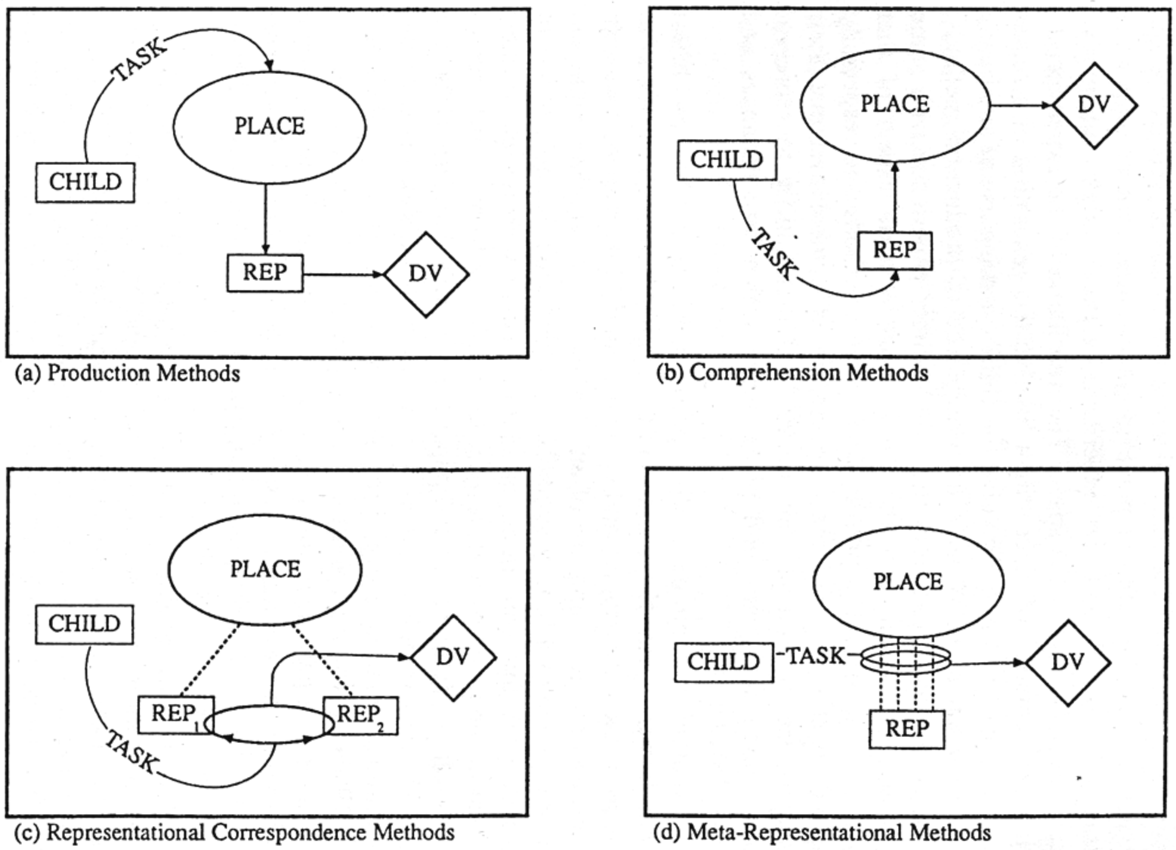


Figure 2. Map showing flag placements (indicated by colored dots), start location (indicated by the "X"), starting facing direction (indicated by arrow), and penny location.

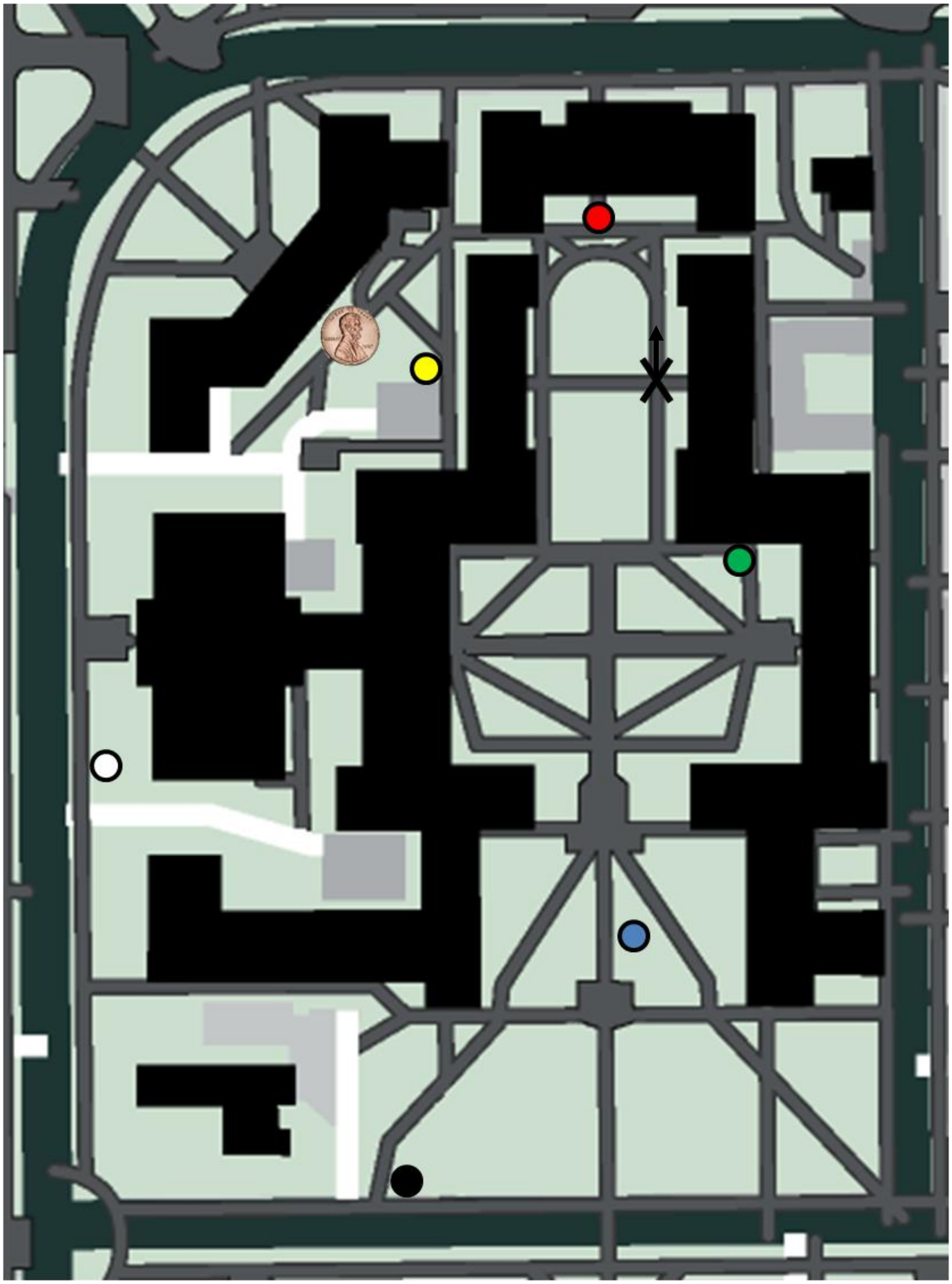


Figure 3. Map showing construction zones. The zone covering the right hand side of the map was inaccessible throughout testing. The zone located in the center of the map was sidewalk repair that was present for about half of the participants. When this construction was occurring participants were able to walk north and south through the middle of the construction.

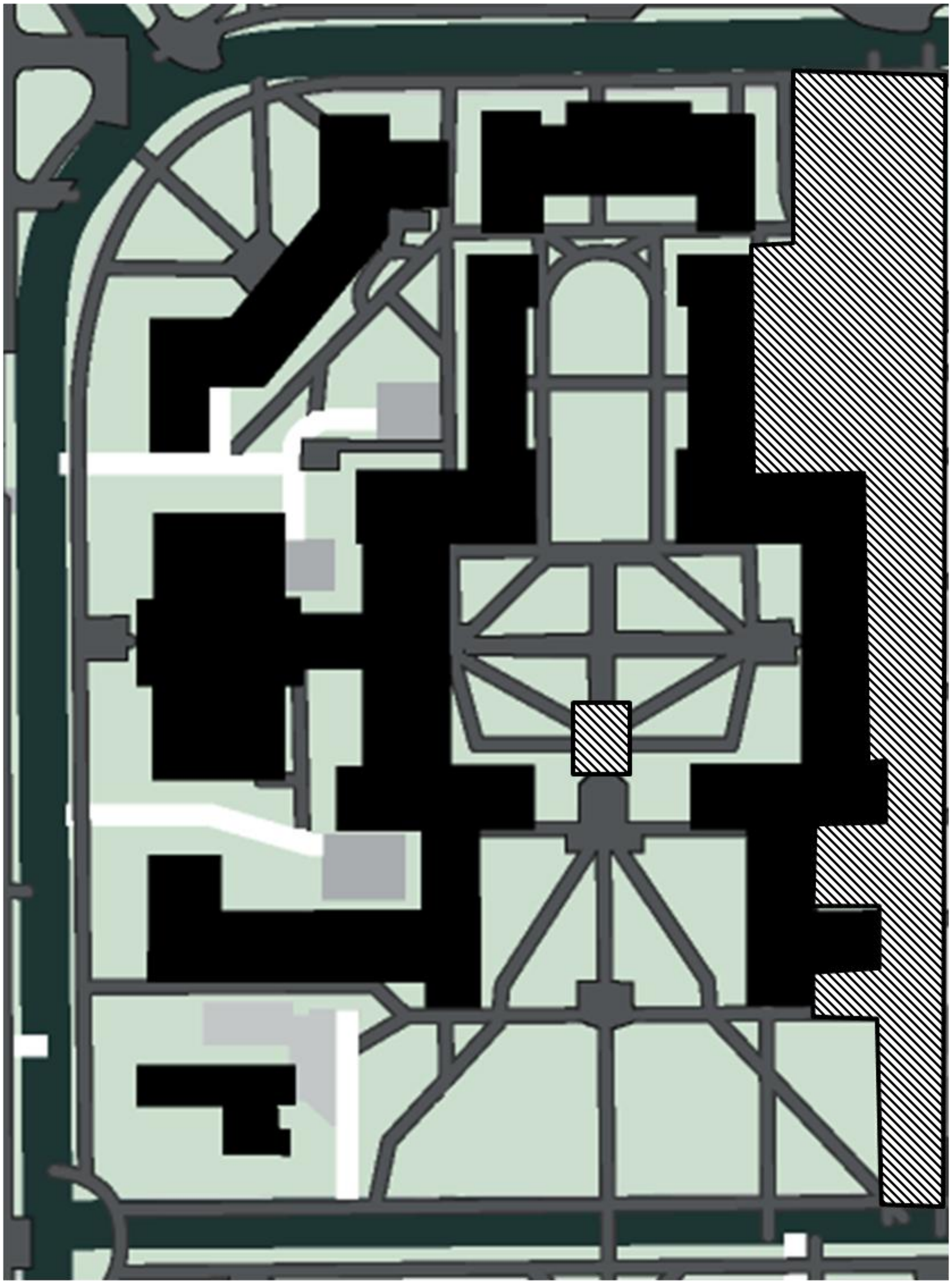


Figure 4. Path taken during the initial walkthrough

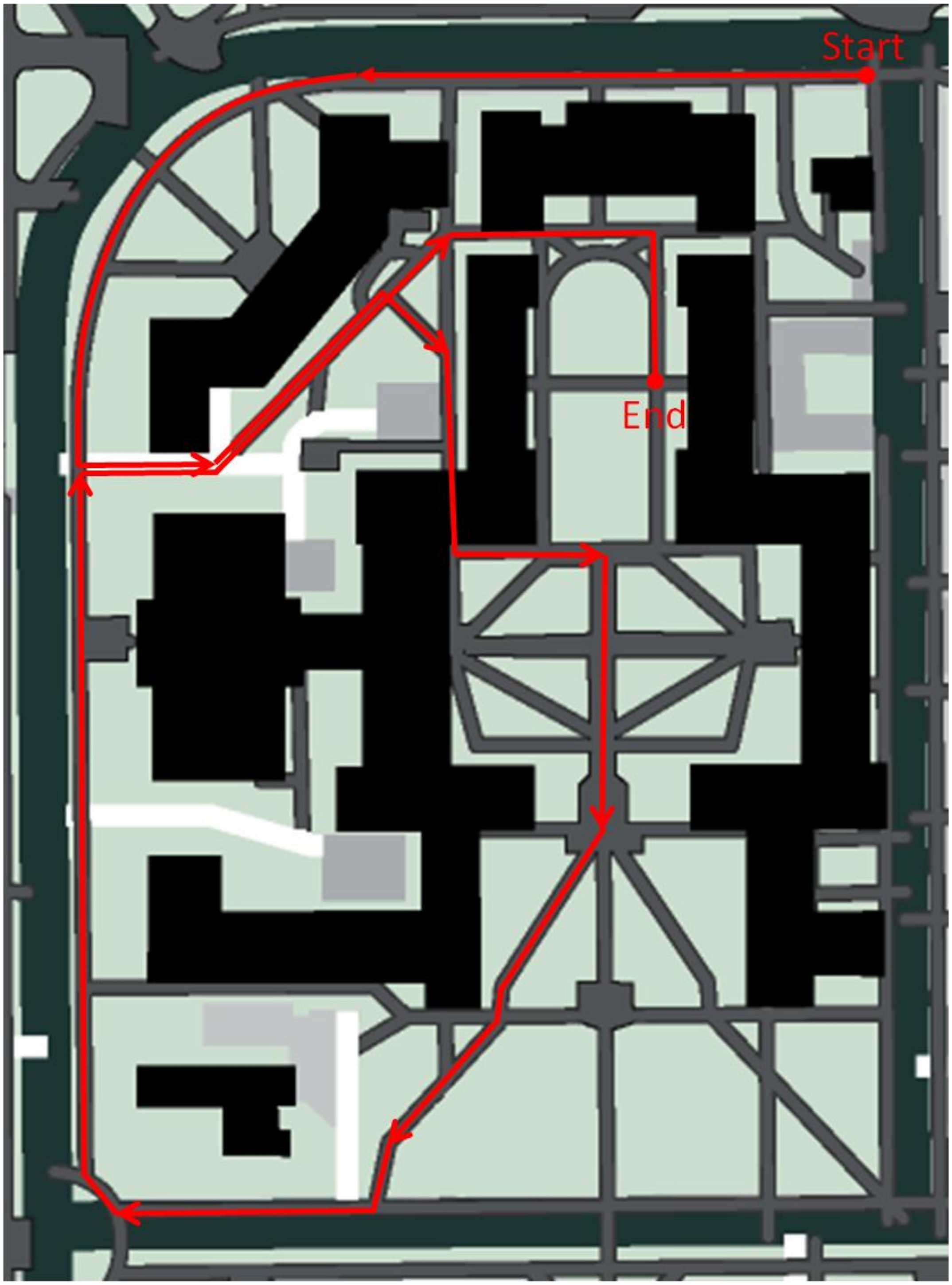


Figure 5. The six colored flags in situ






Figure 6. Pointing locations and path taken between locations.

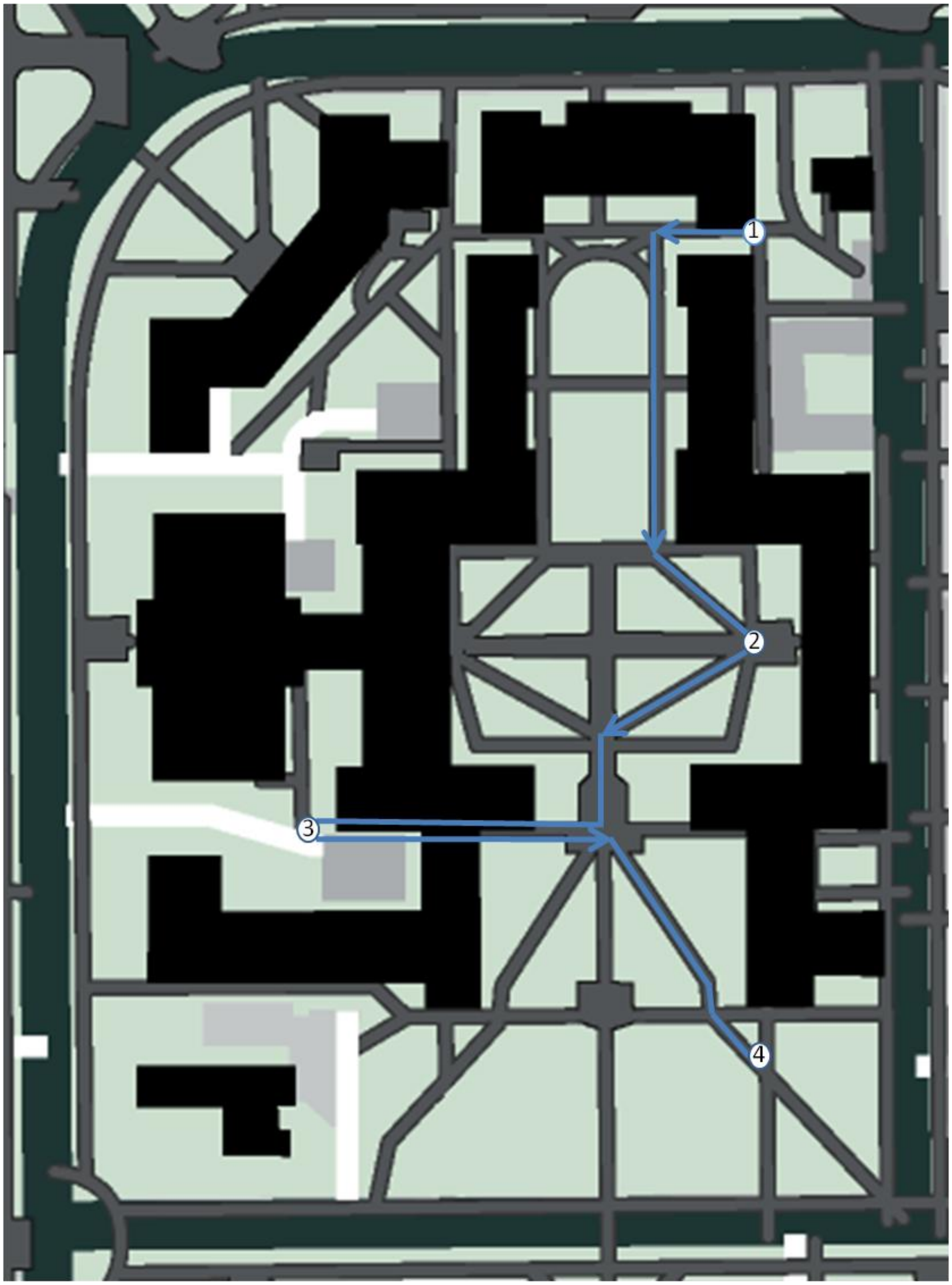


Figure 7. Split screen showing all three video angles.

Figure 8.1. Composite map of answers to the red flag collapsed across all participants.

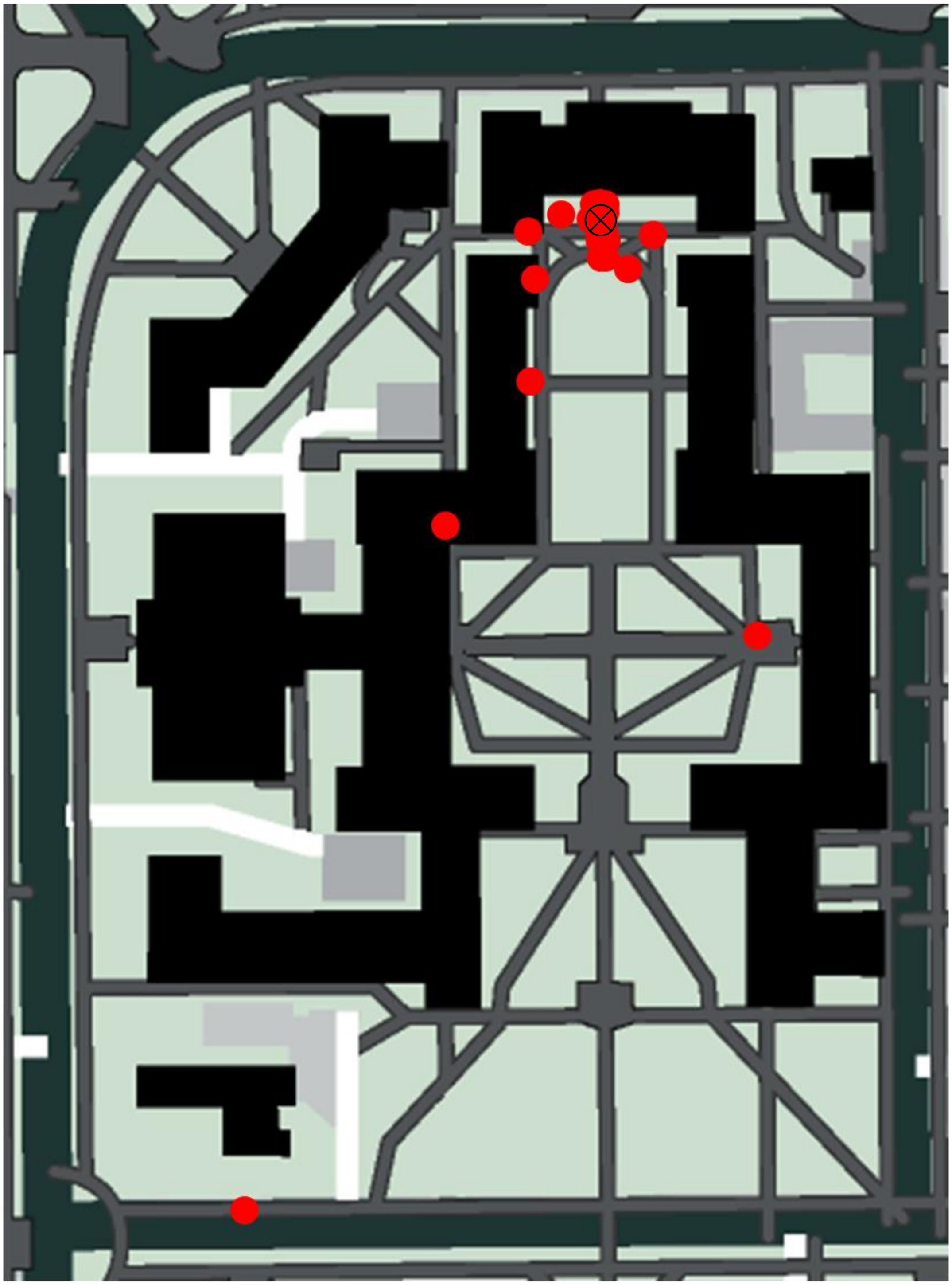


Figure 8.2. Composite map of answers to the green flag collapsed across all participants.

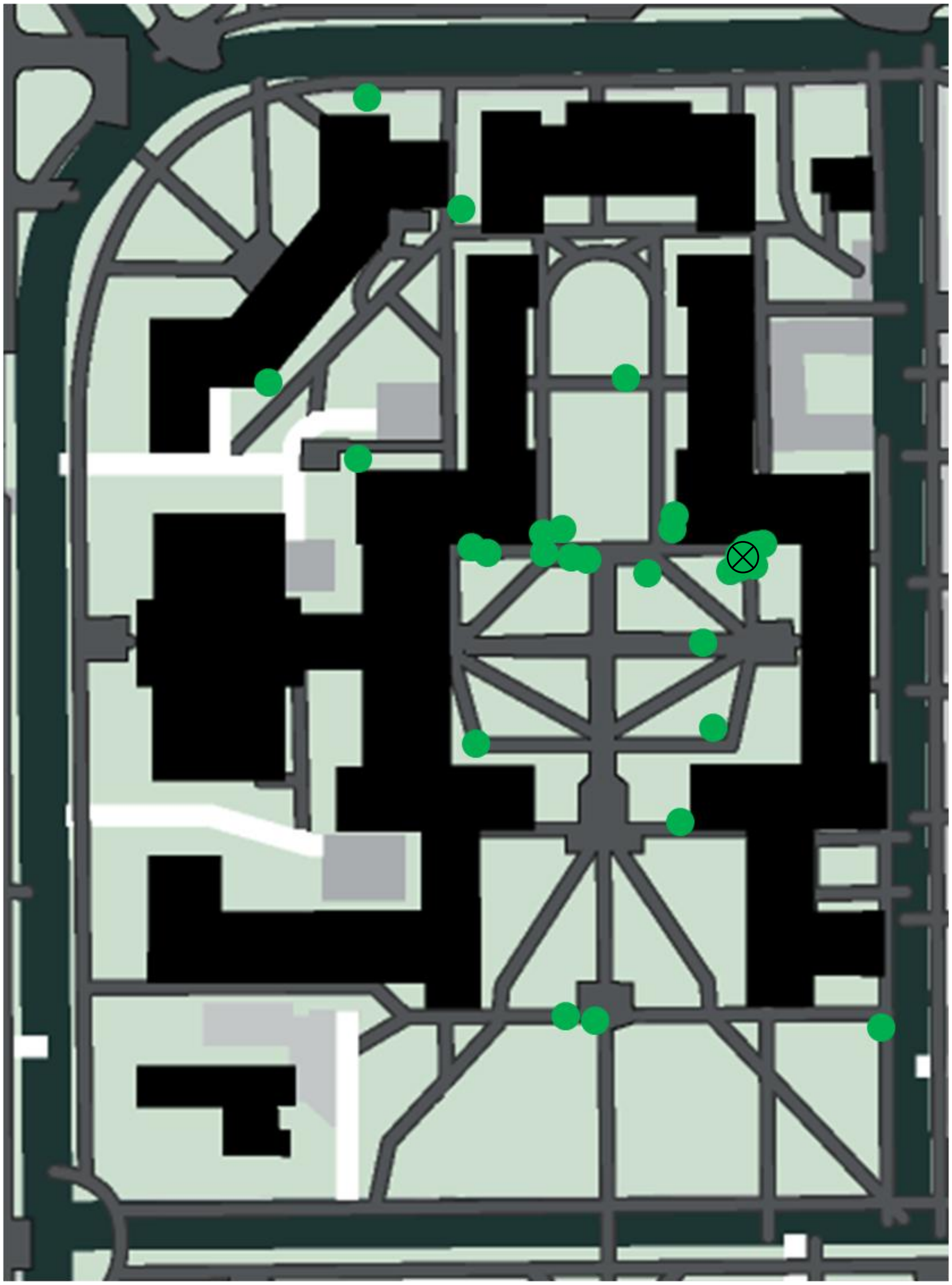


Figure 8.3. Composite map of answers to the blue flag collapsed across all participants.

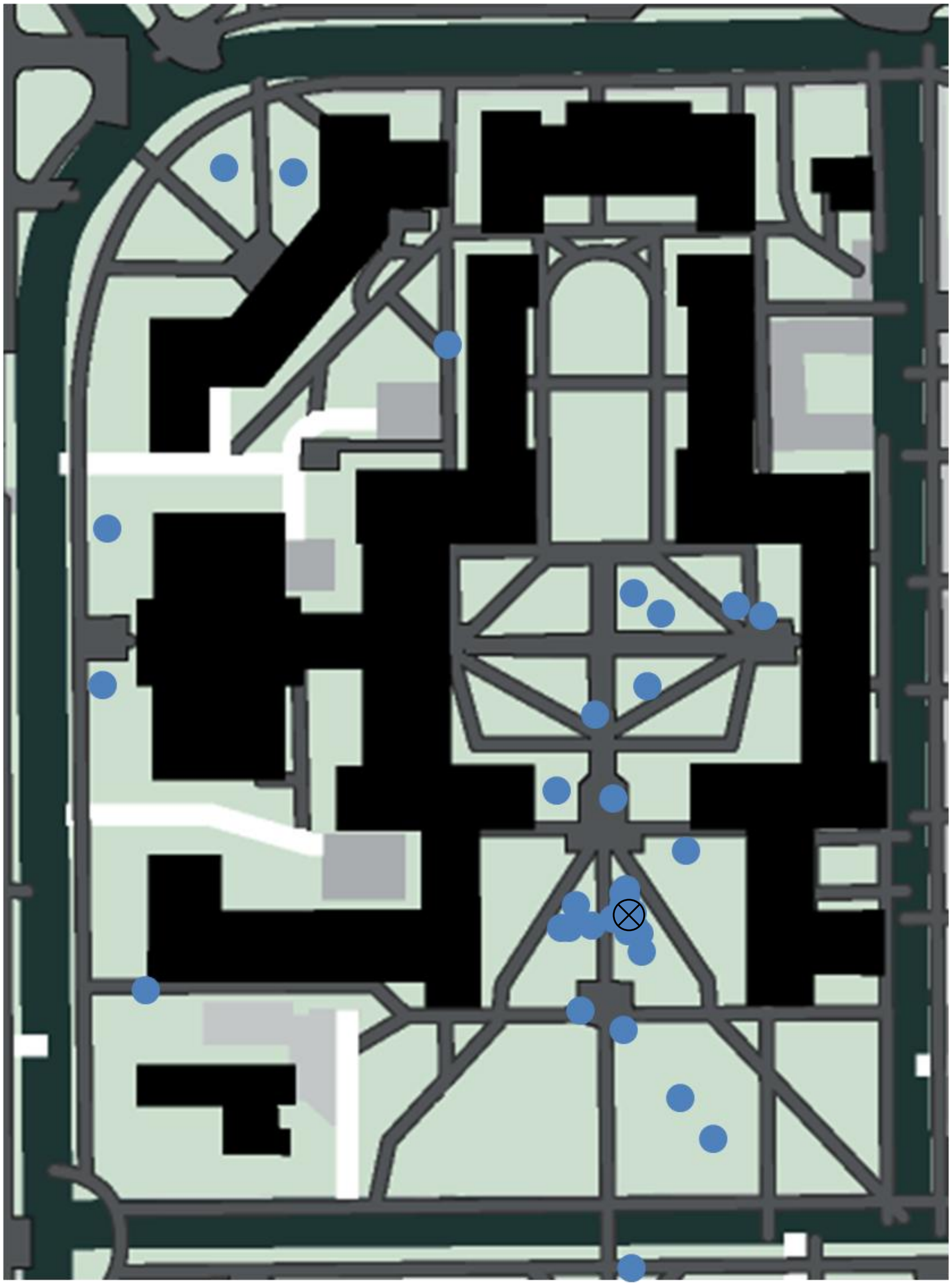


Figure 8.4. Composite map of answers to the black flag collapsed across all participants.

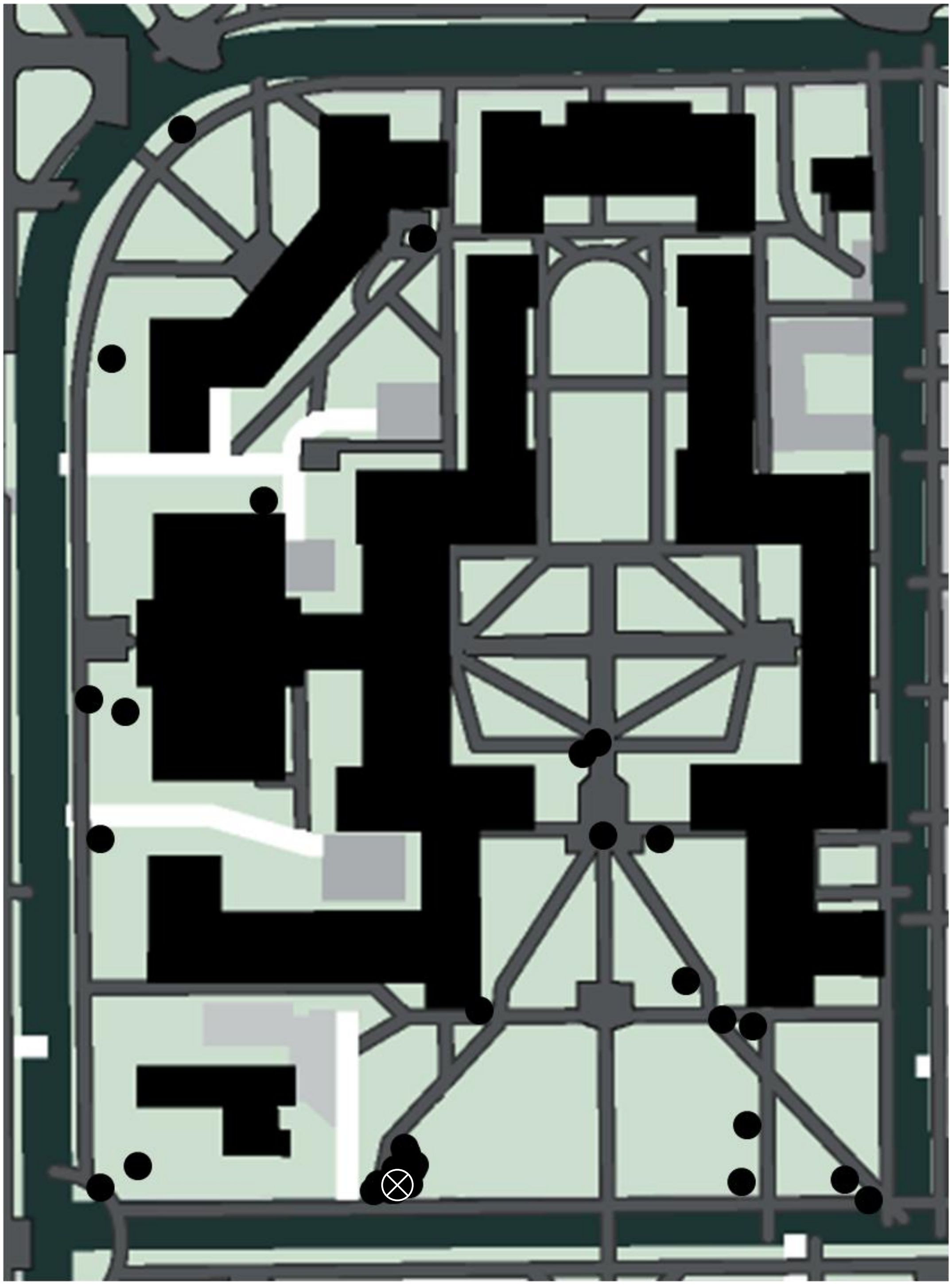


Figure 8.5. Composite map of answers to the white flag collapsed across all participants.

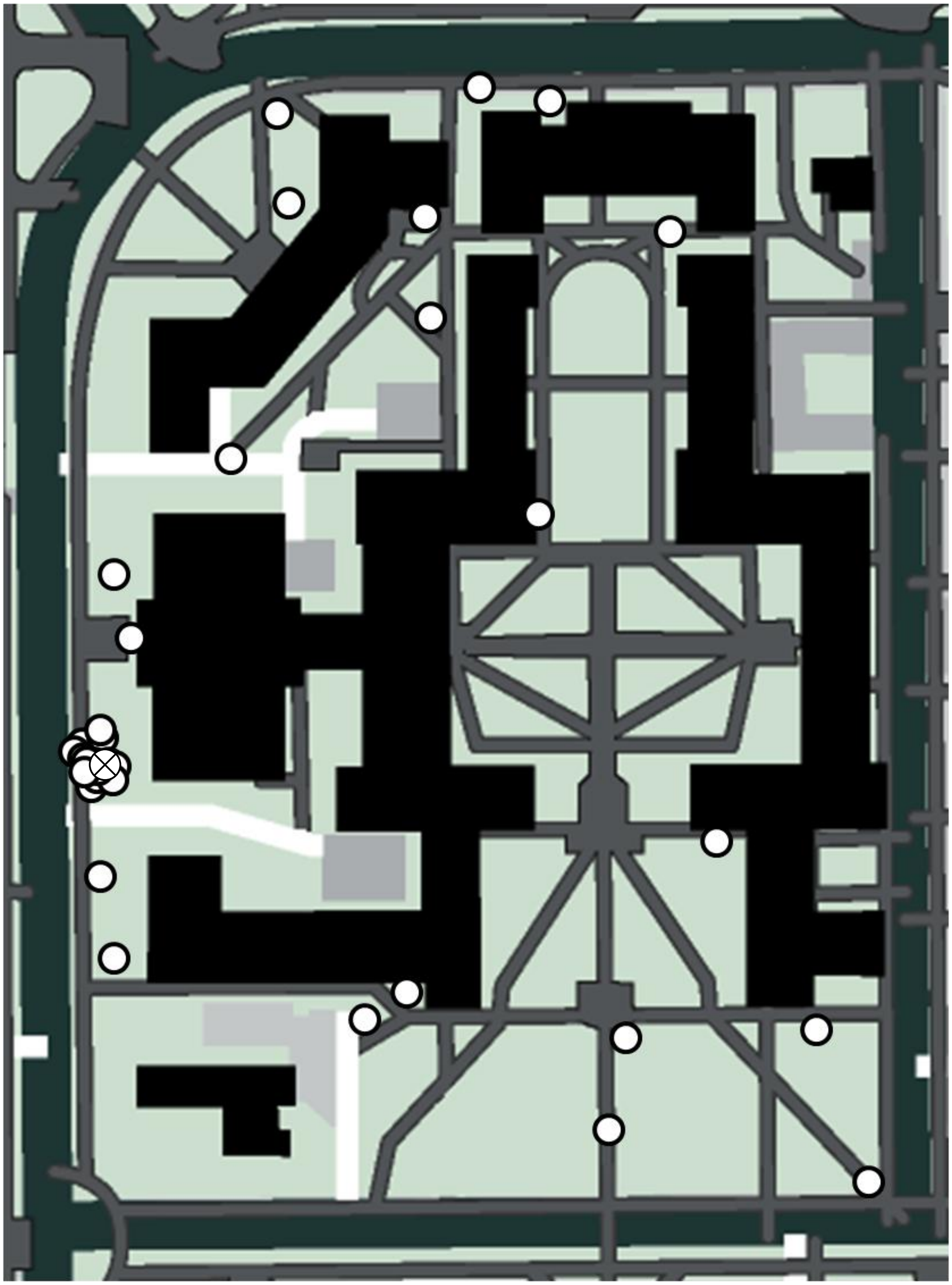


Figure 8.6. Composite map of answers to the yellow flag collapsed across all participants.

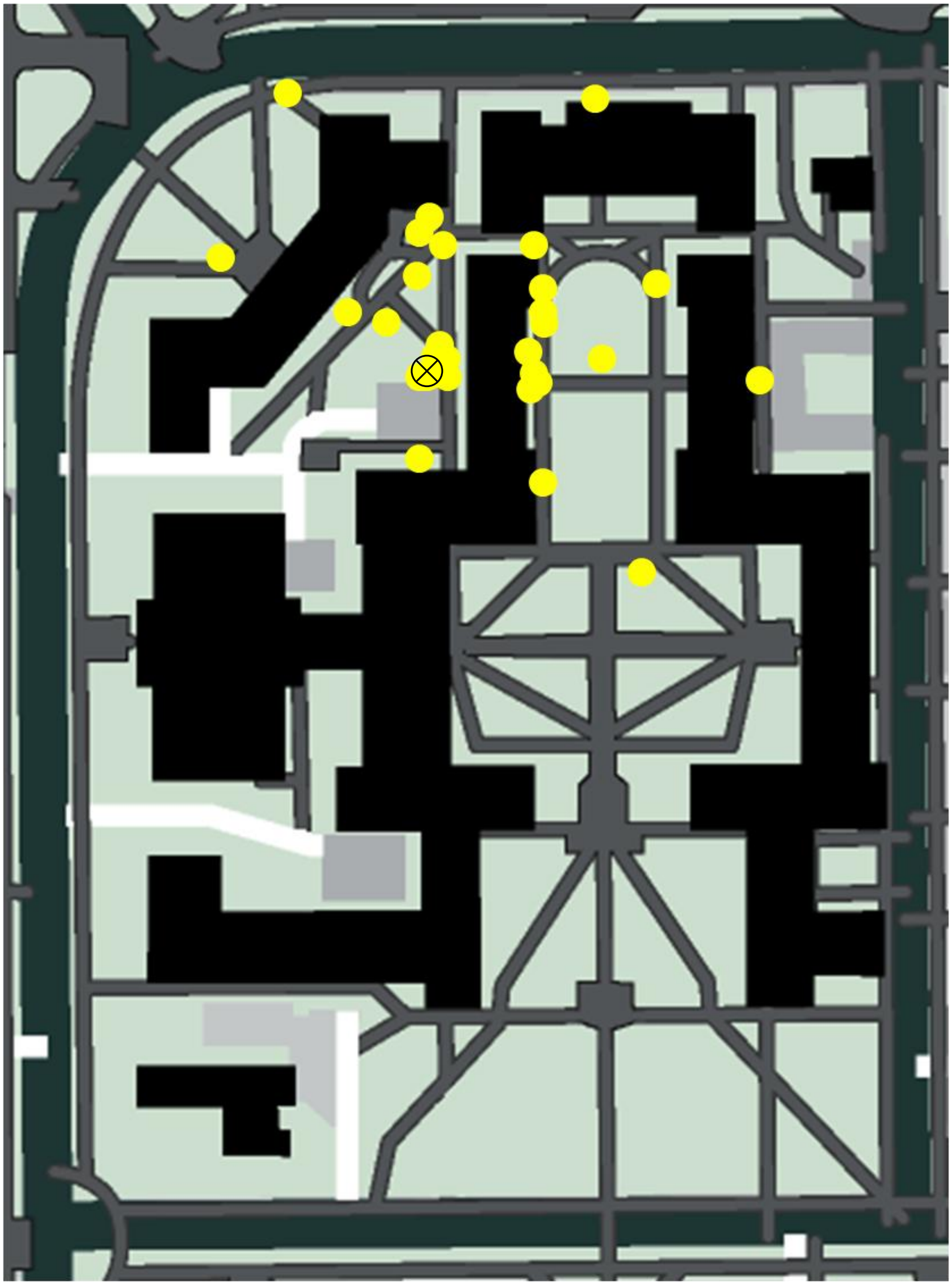


Figure 8.7. Composite map of answers to the red flag from the comprehension group.

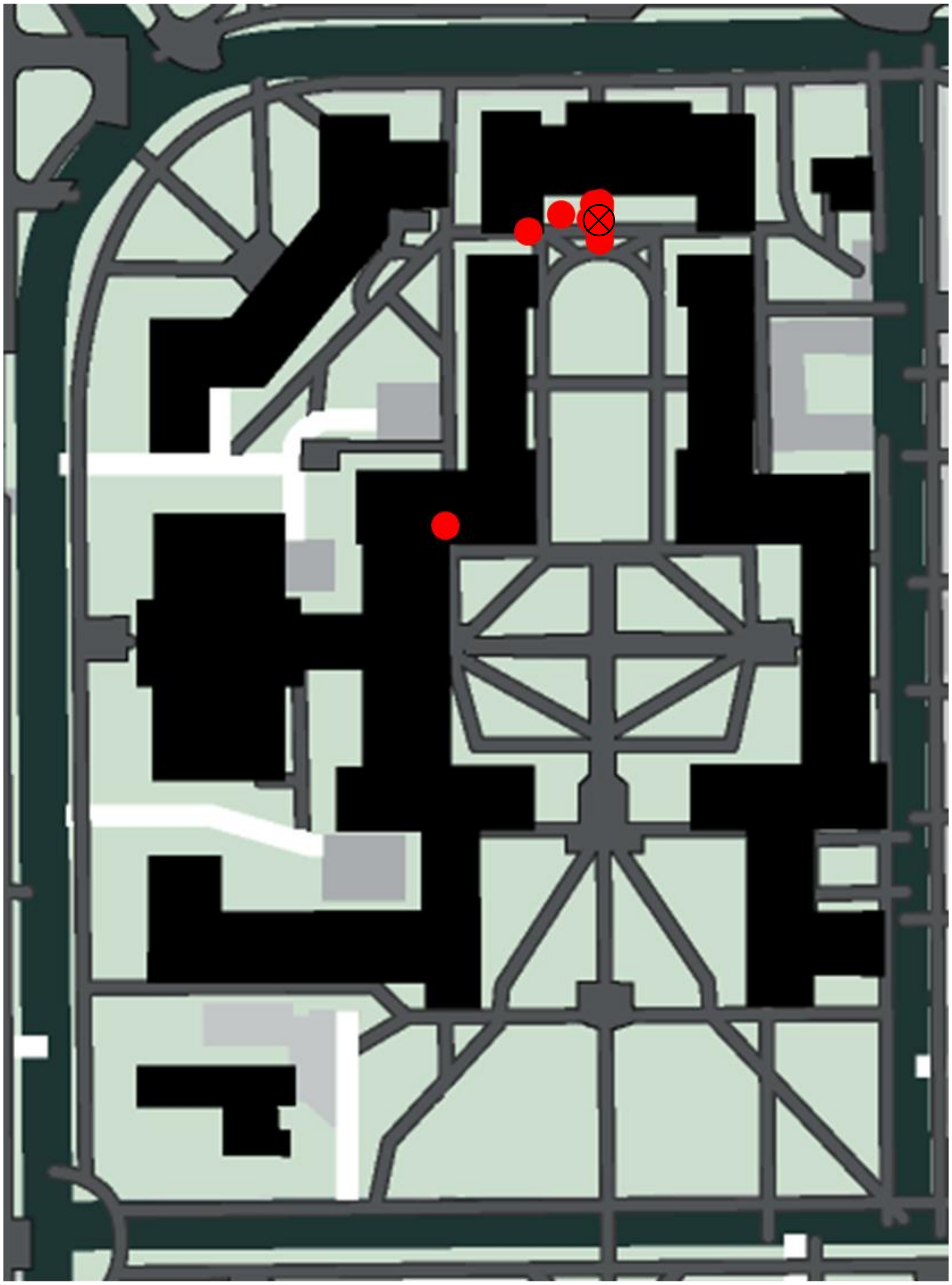


Figure 8.8. Composite map of answers to the green flag from the comprehension group.

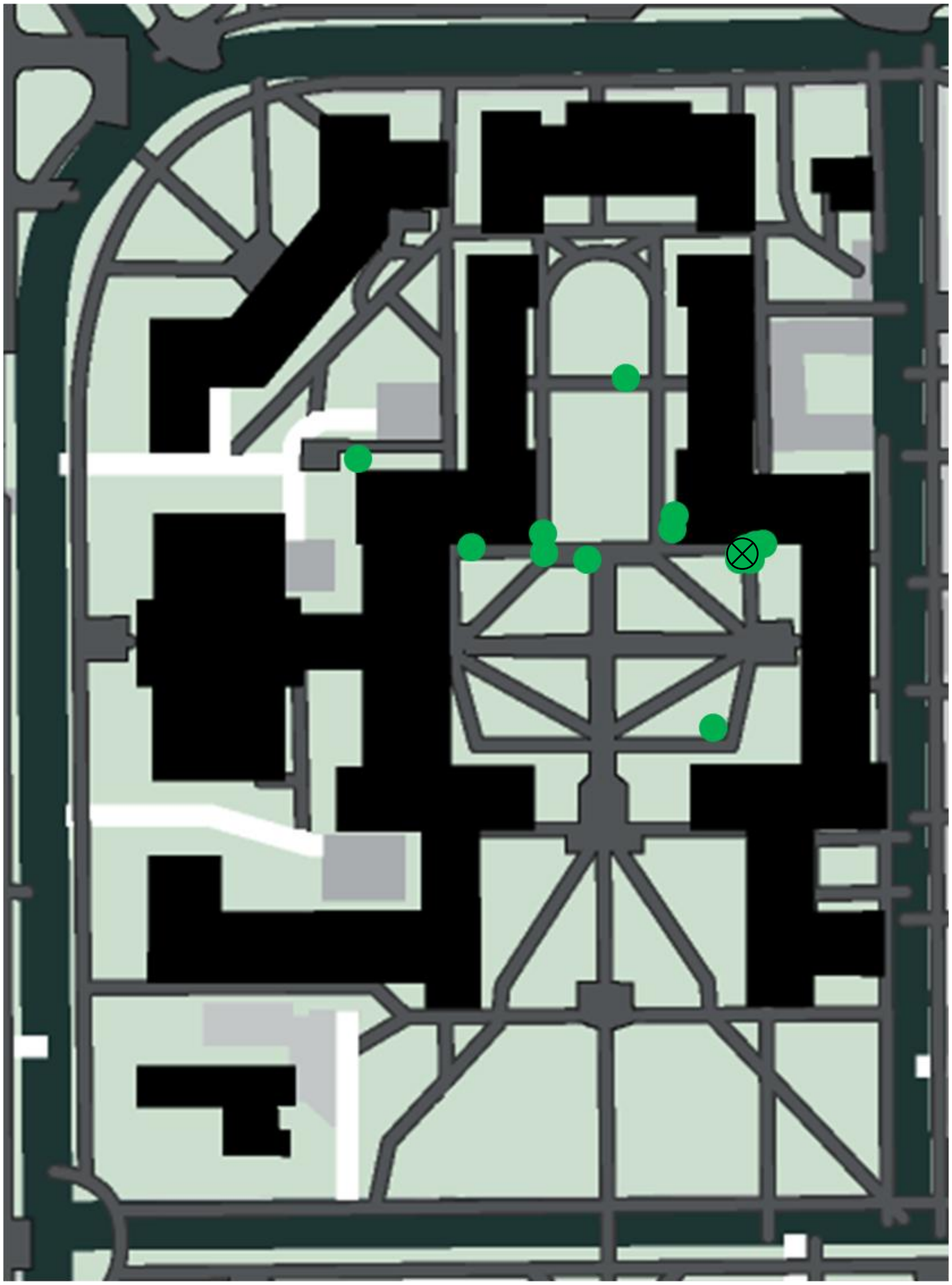


Figure 8.9. Composite map of answers to the blue flag from the comprehension group.

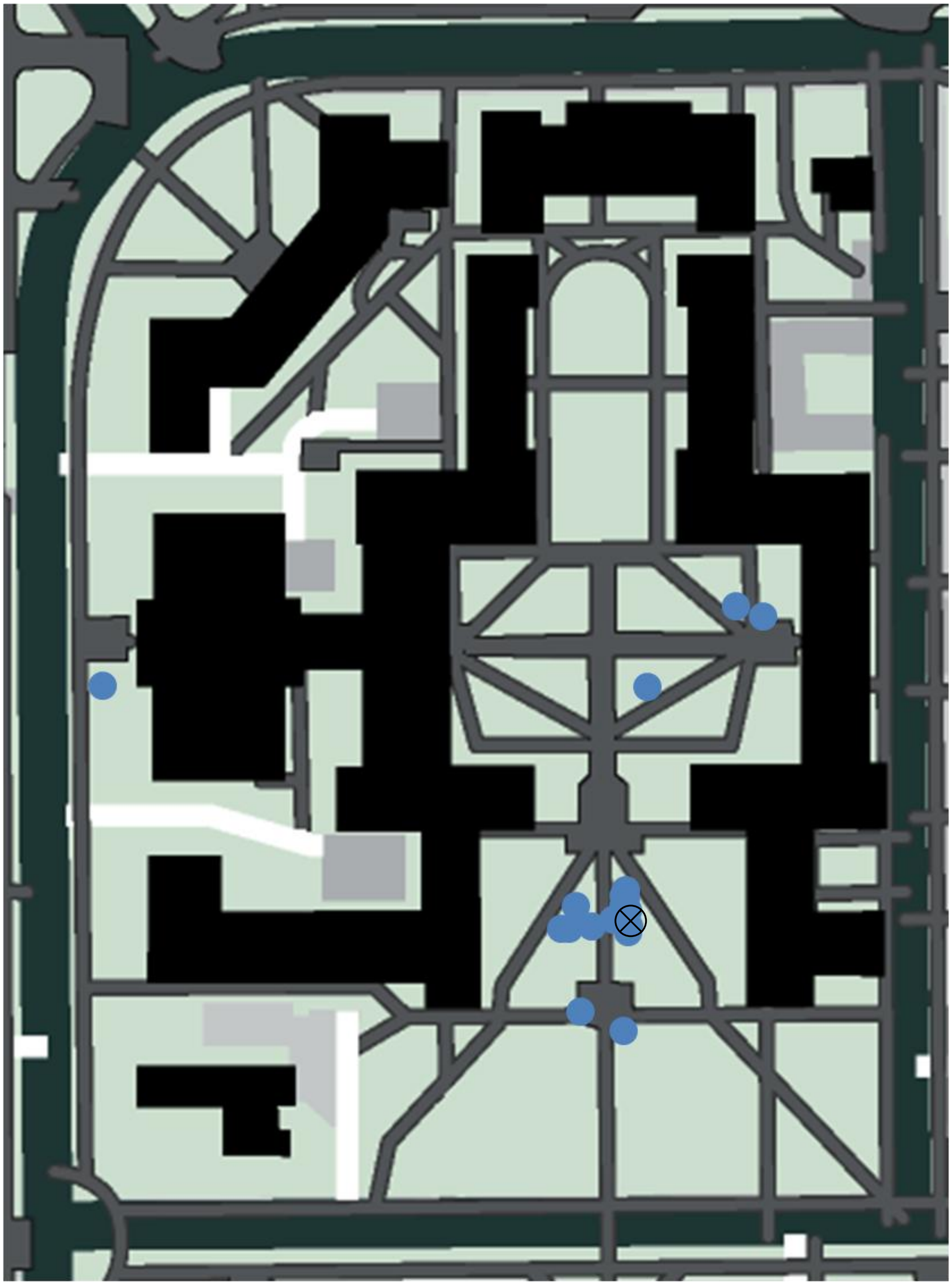


Figure 8.10. Composite map of answers to the black flag from the comprehension group.

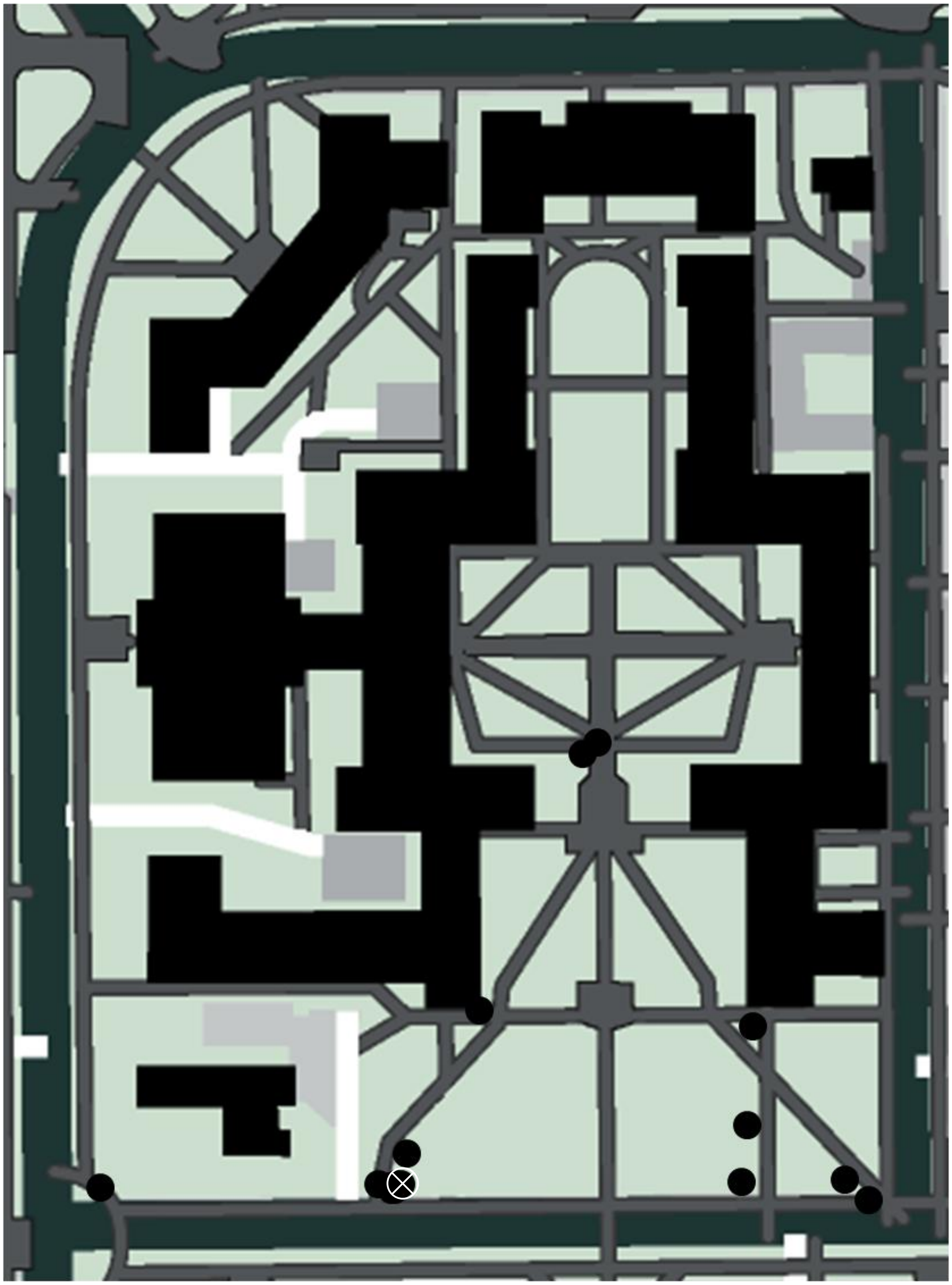


Figure 8.11. Composite map of answers to the white flag from the comprehension group.

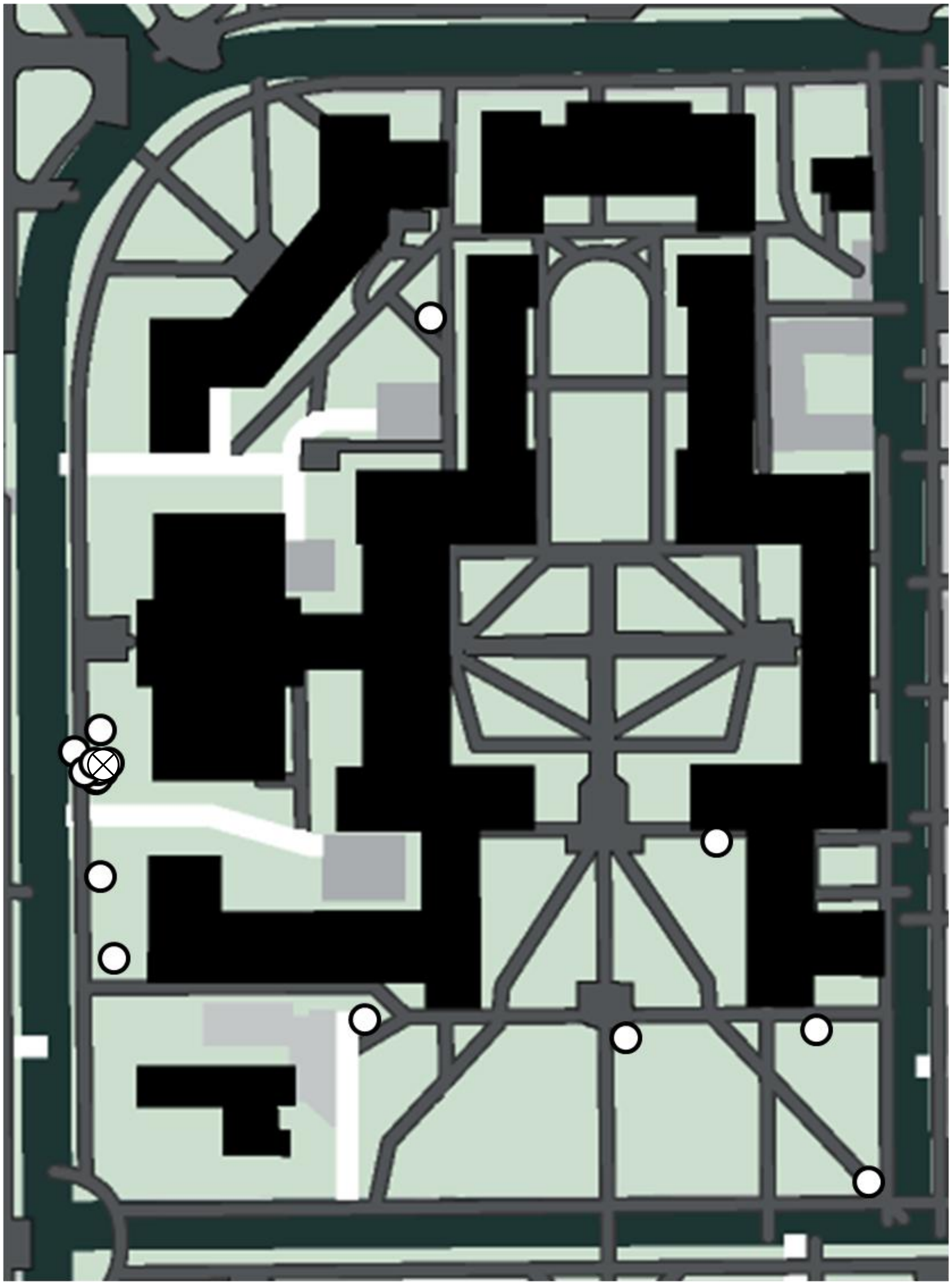


Figure 8.12. Composite map of answers to the yellow flag from the comprehension group.

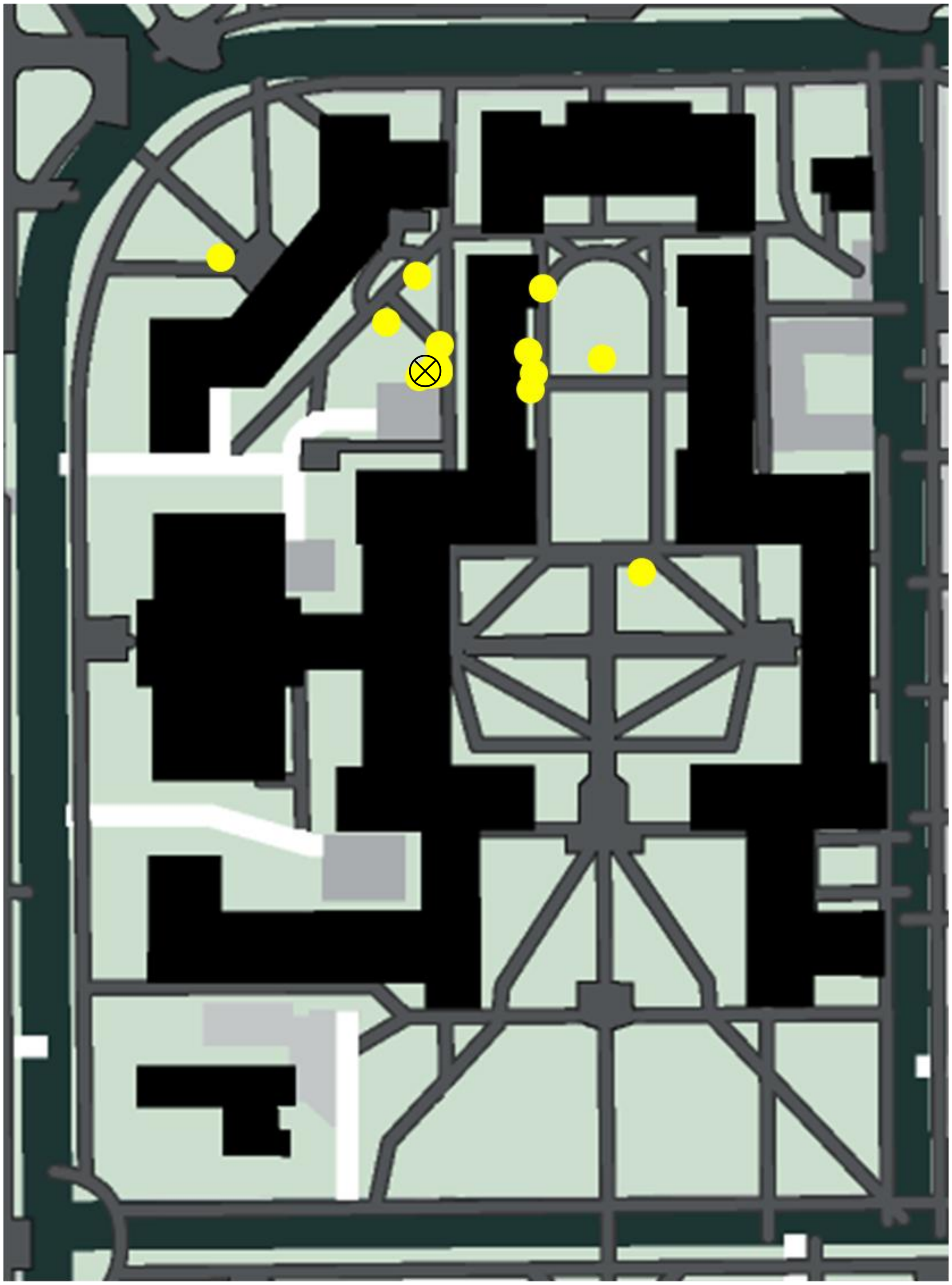


Figure 8.13. Composite map of answers to the red flag from the production group.

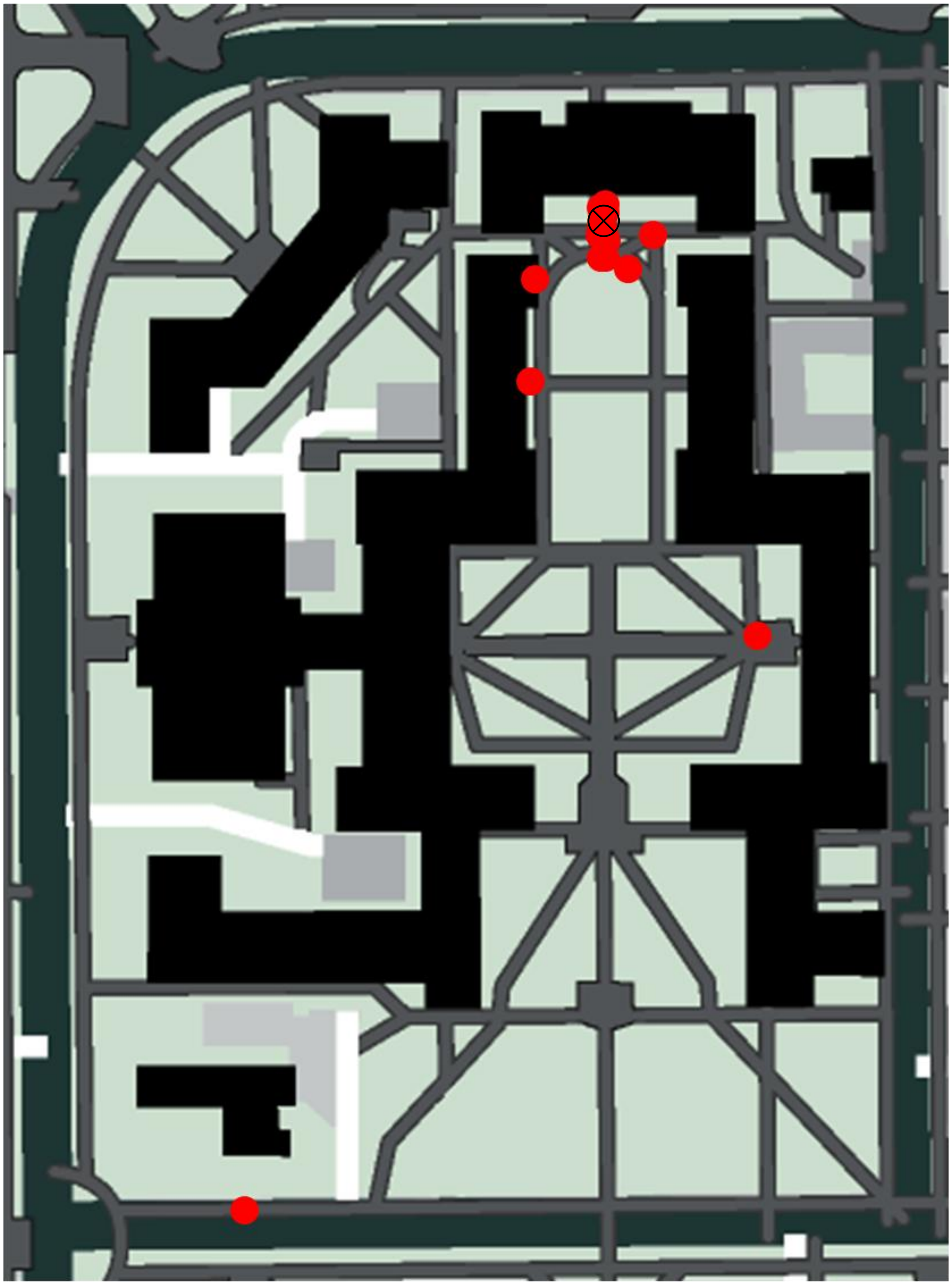


Figure 8.14. Composite map of answers to the green flag from the production group.

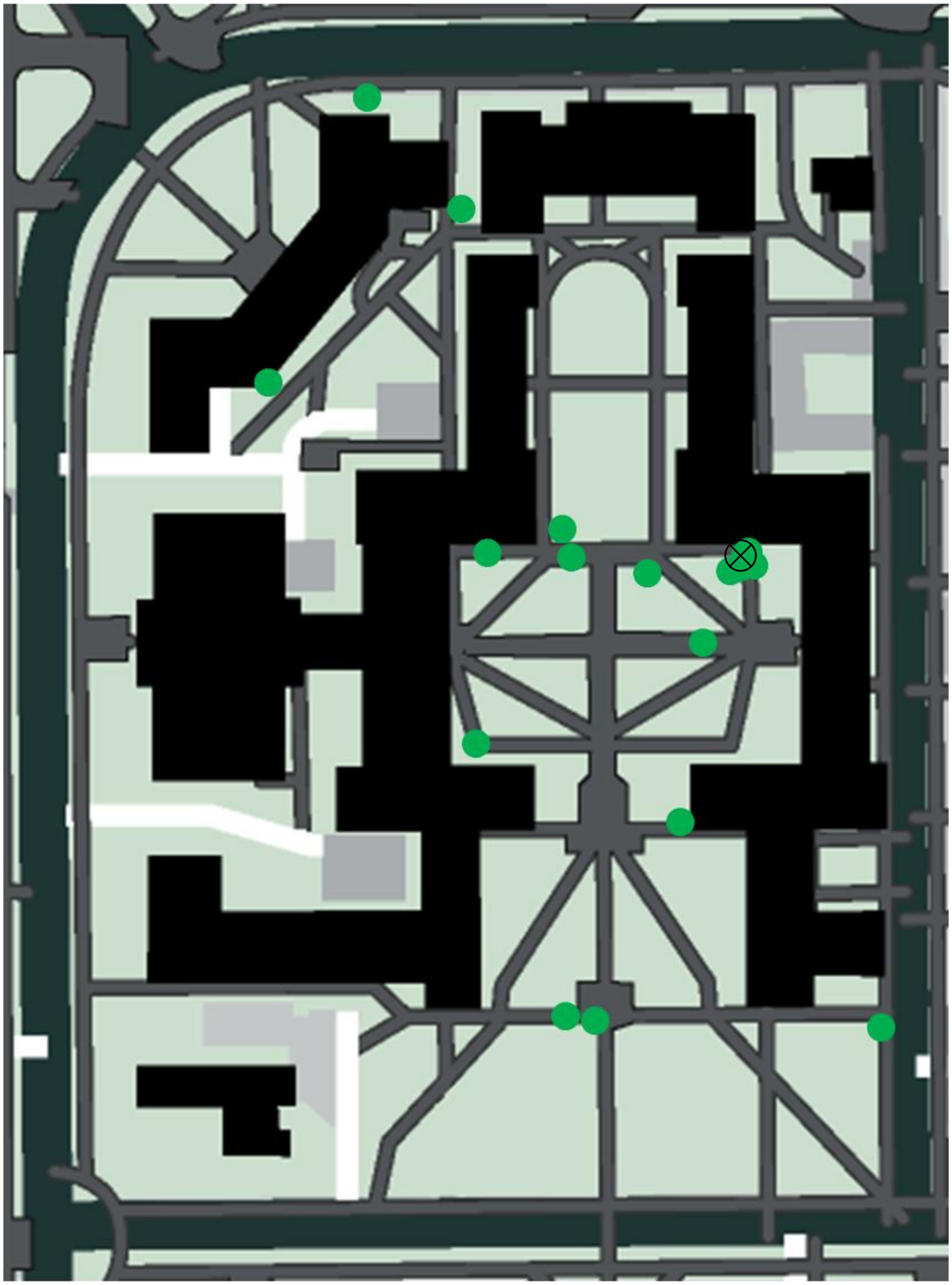


Figure 8.15. Composite map of answers to the blue flag from the production group.

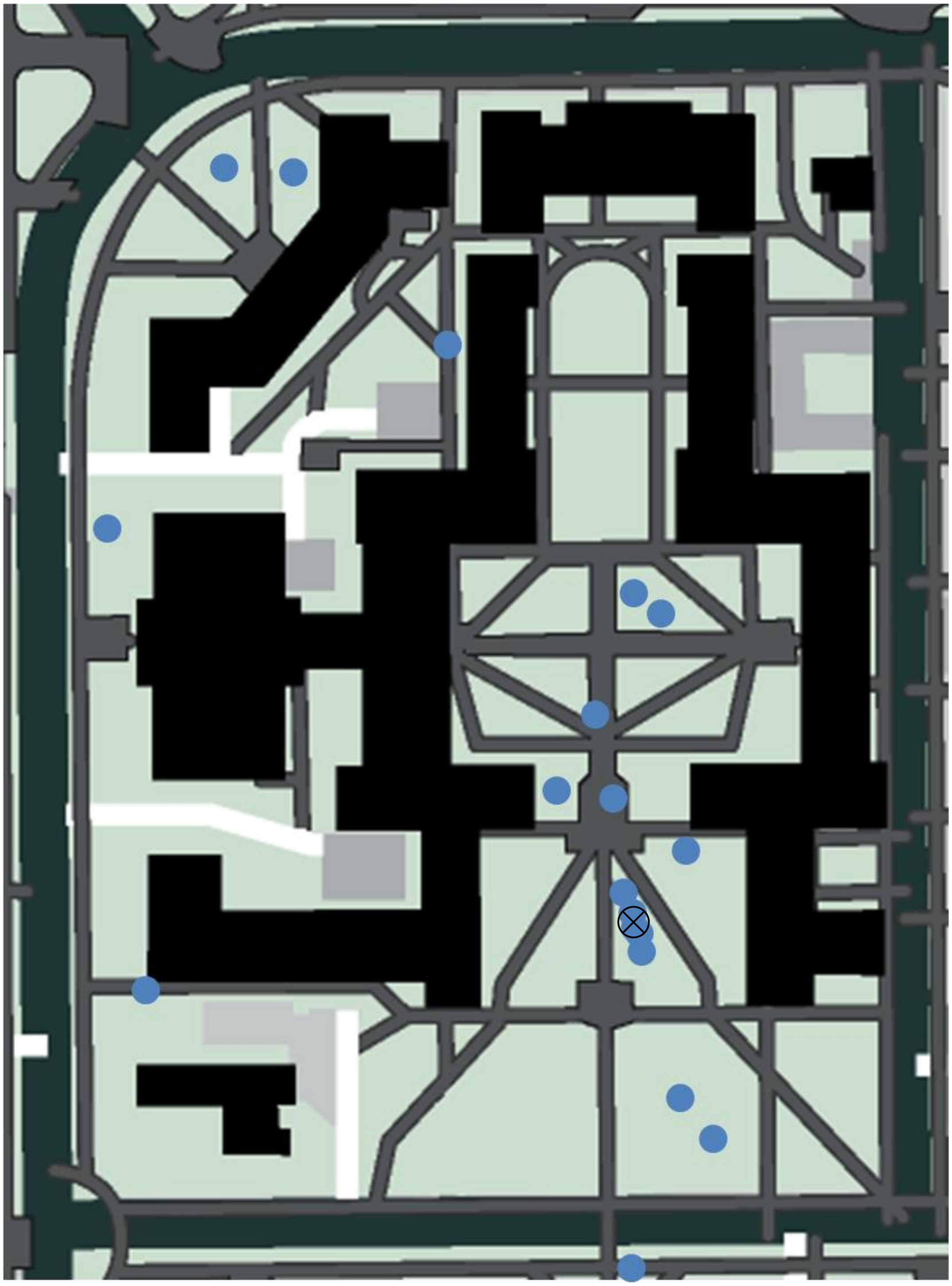


Figure 8.16. Composite map of answers to the black flag from the production group.

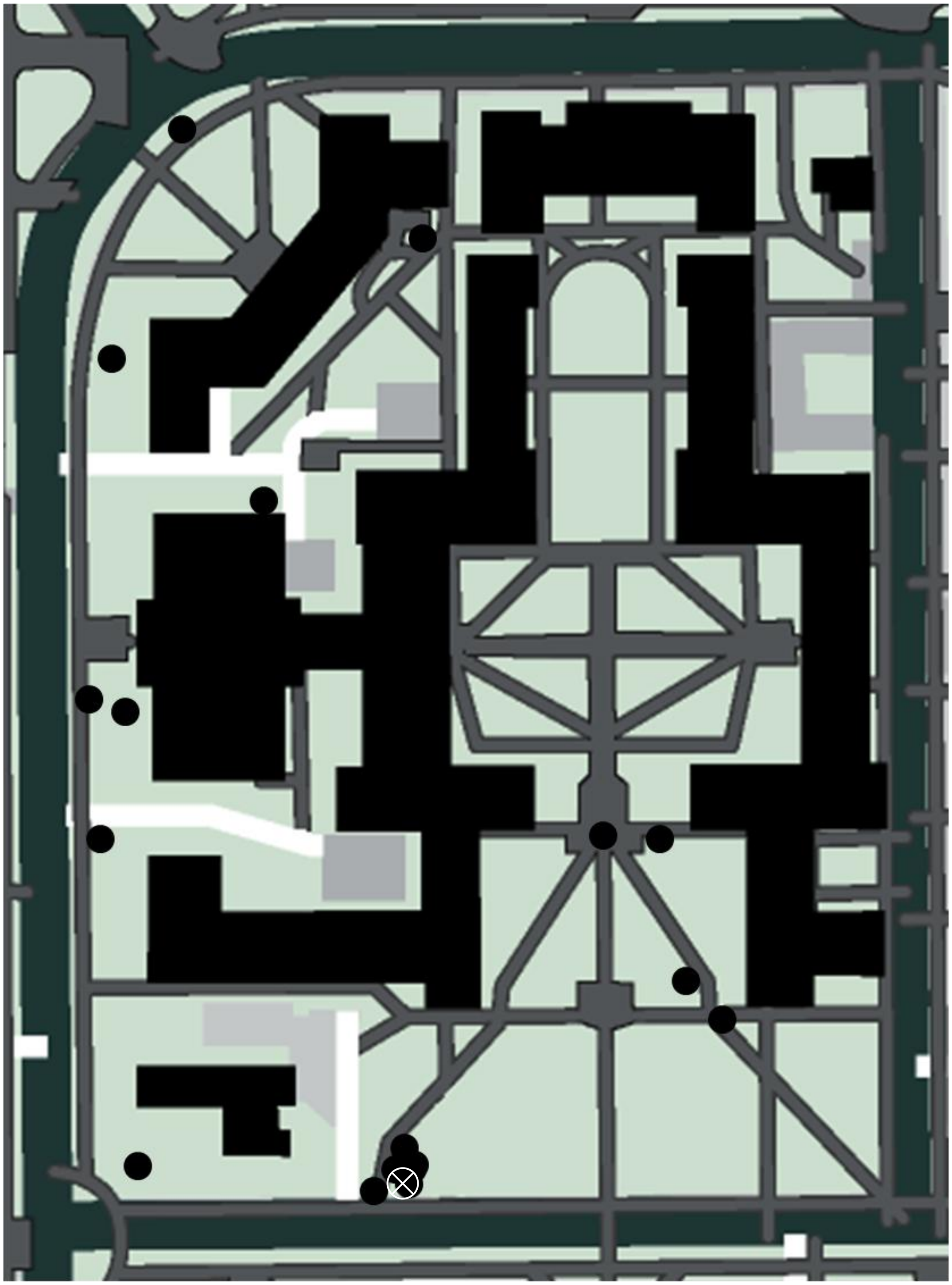


Figure 8.17. Composite map of answers to the white flag from the production group.

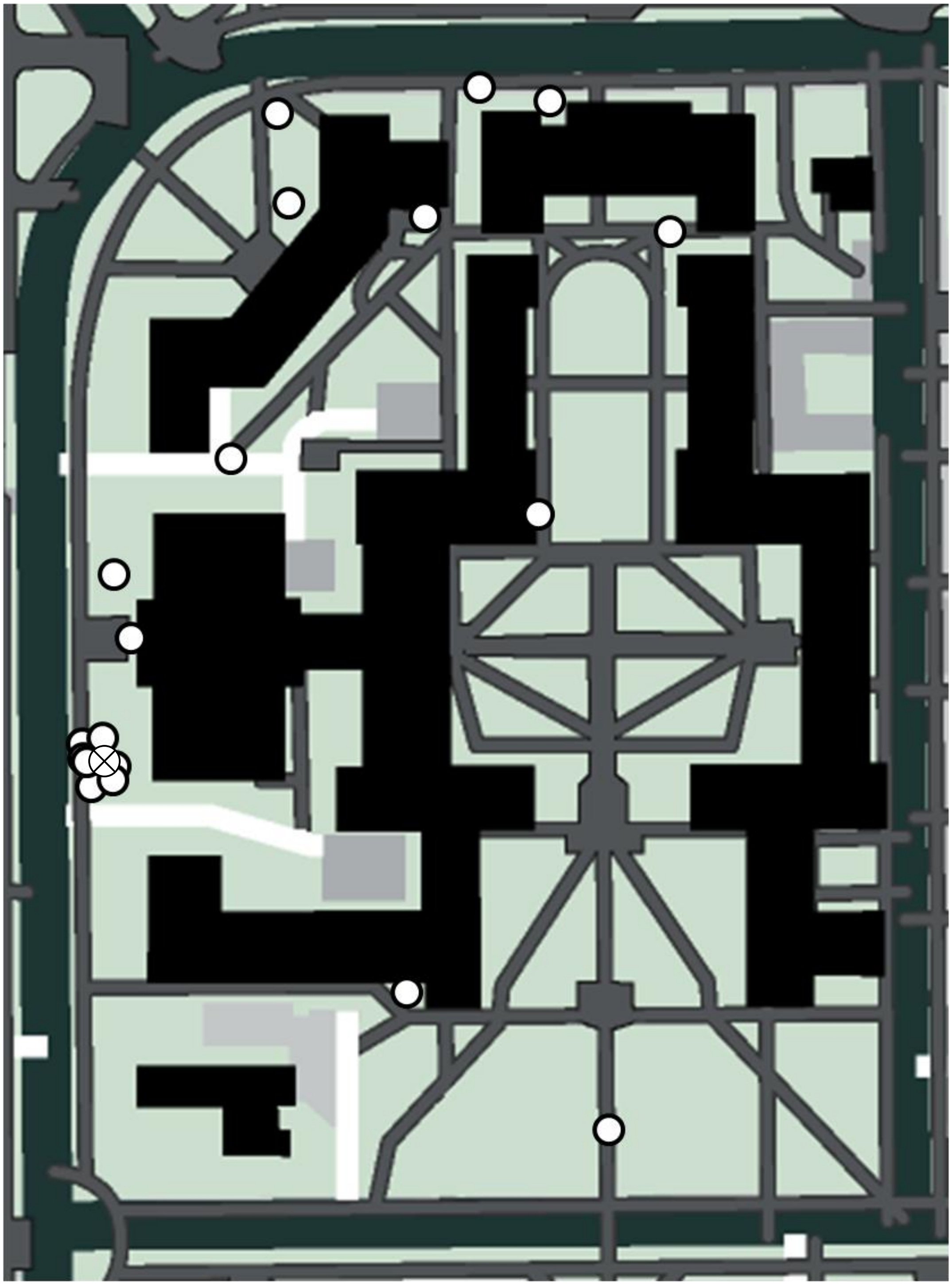


Figure 8.18. Composite map of answers to the yellow flag from the production group.

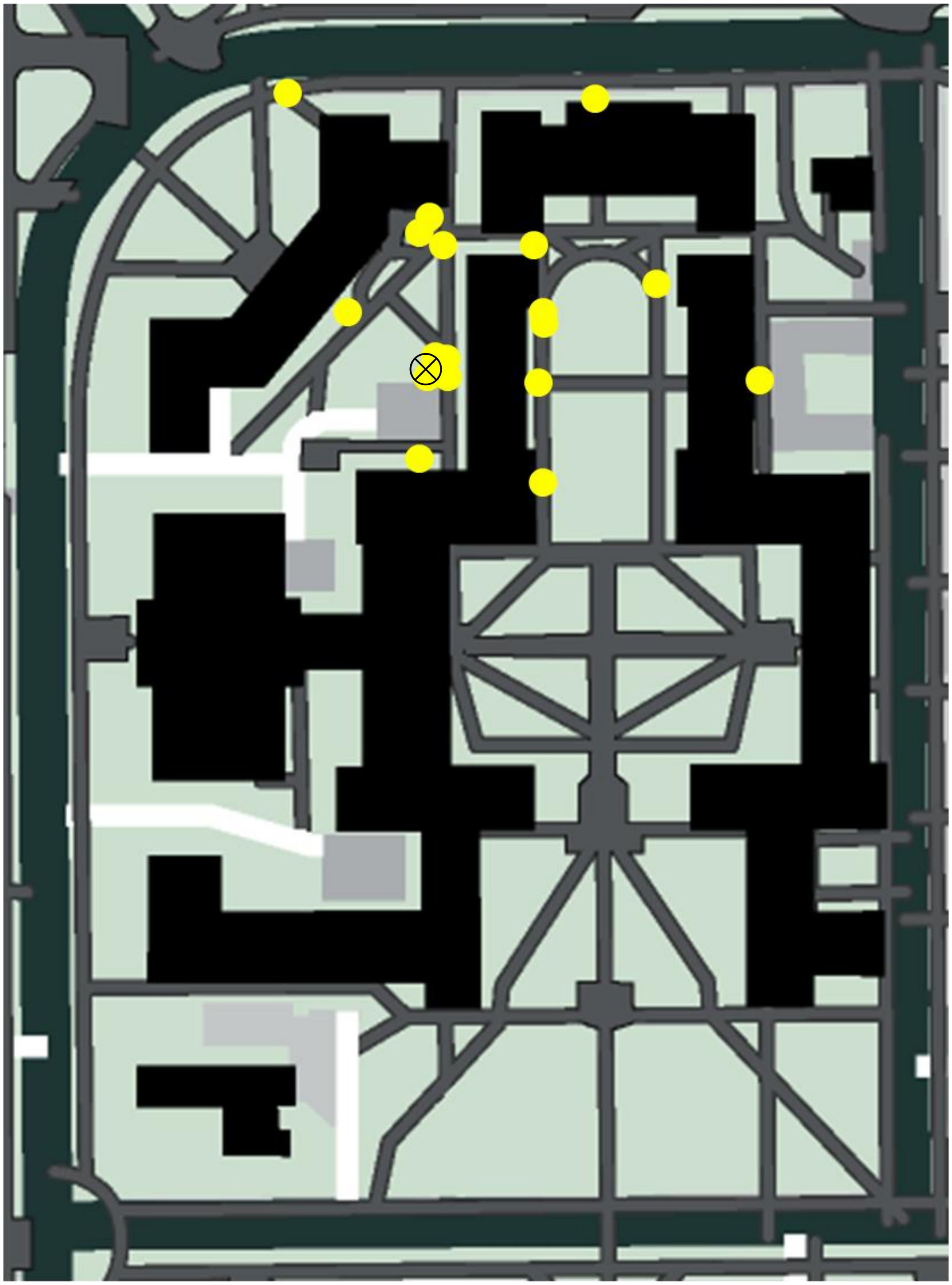


Figure 8.19. Composite map of answers to the red flag for boys.

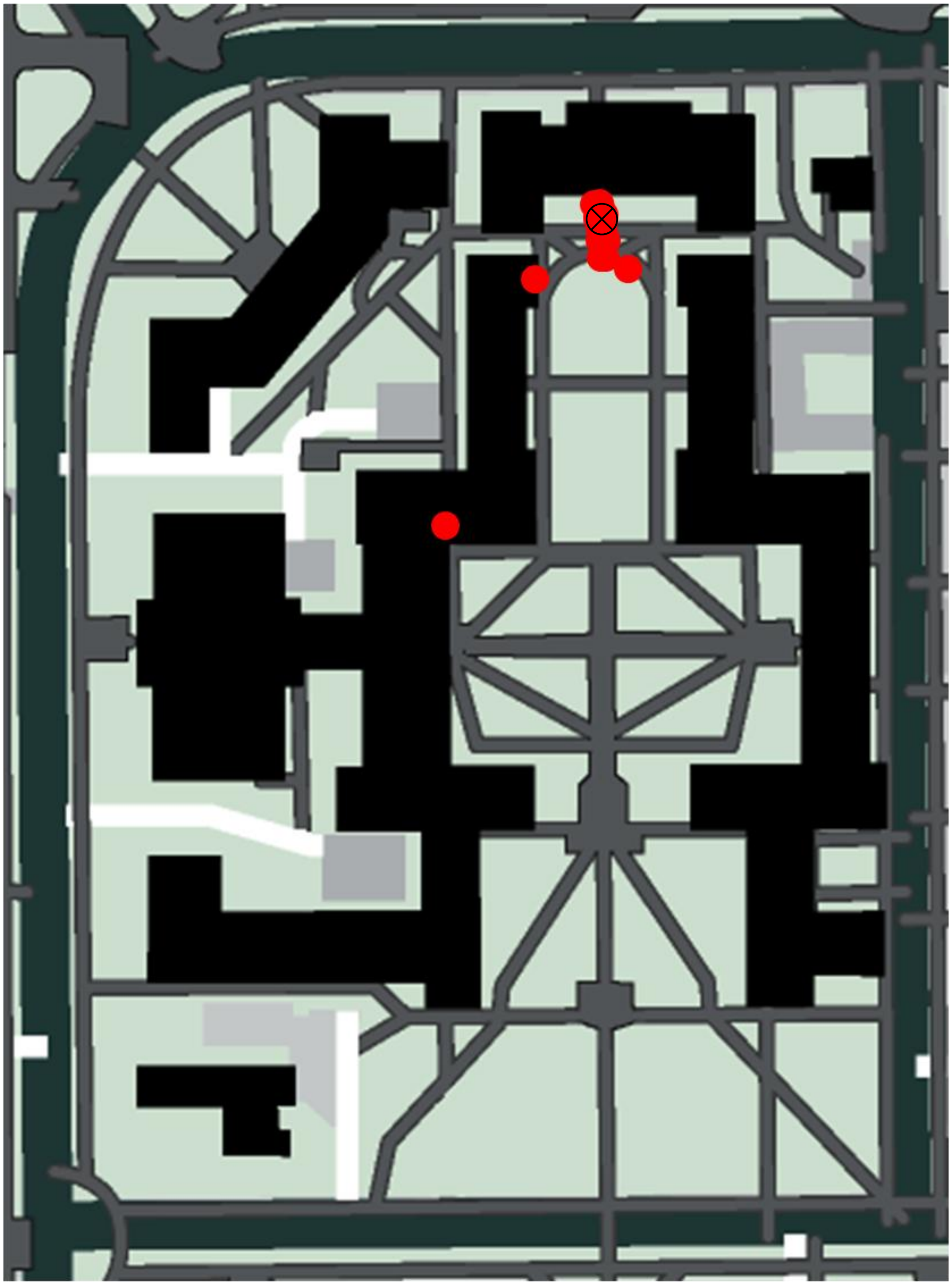


Figure 8.20. Composite map of answers to the green flag for boys.

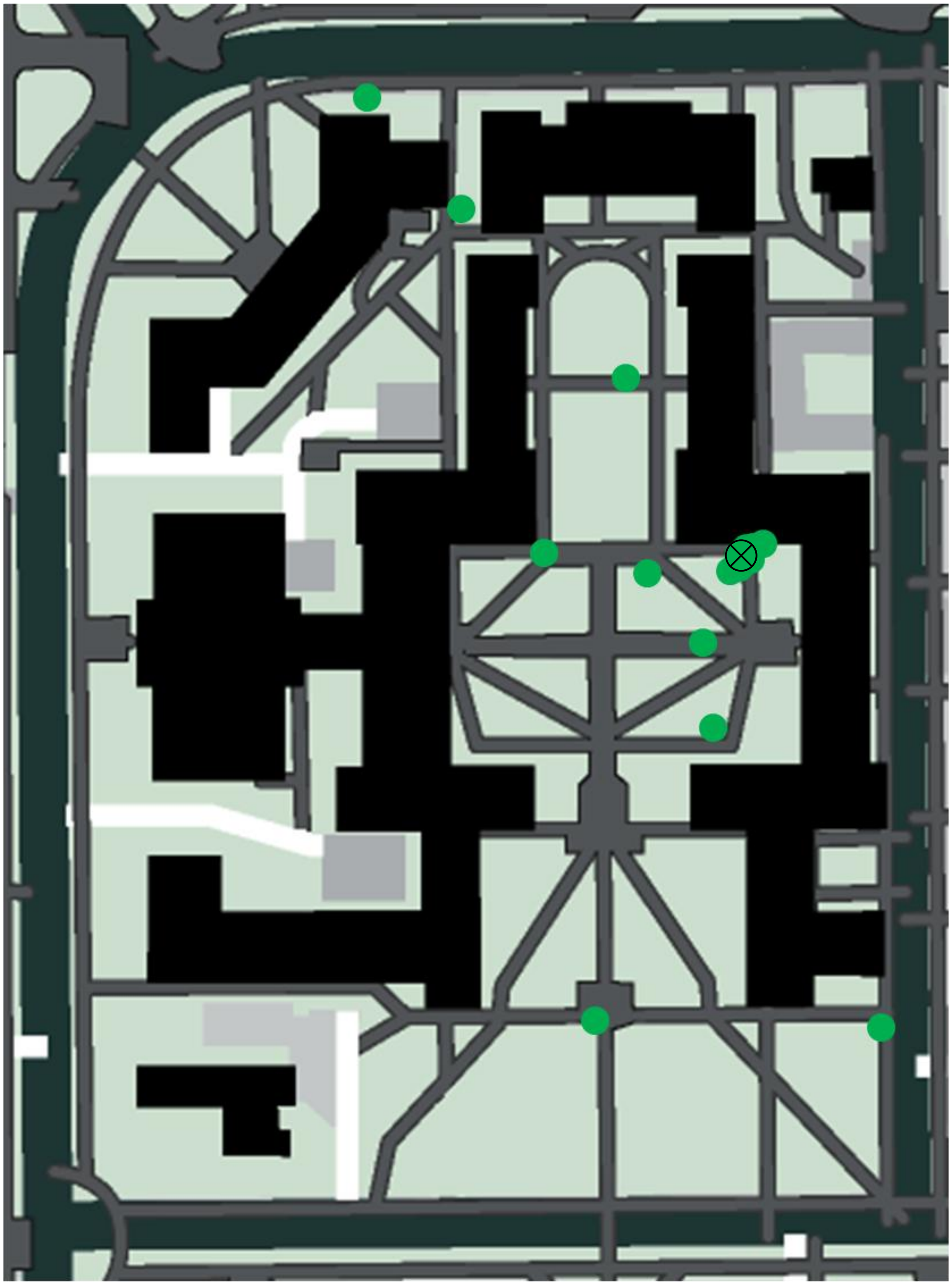


Figure 8.21. Composite map of answers to the blue flag for boys.

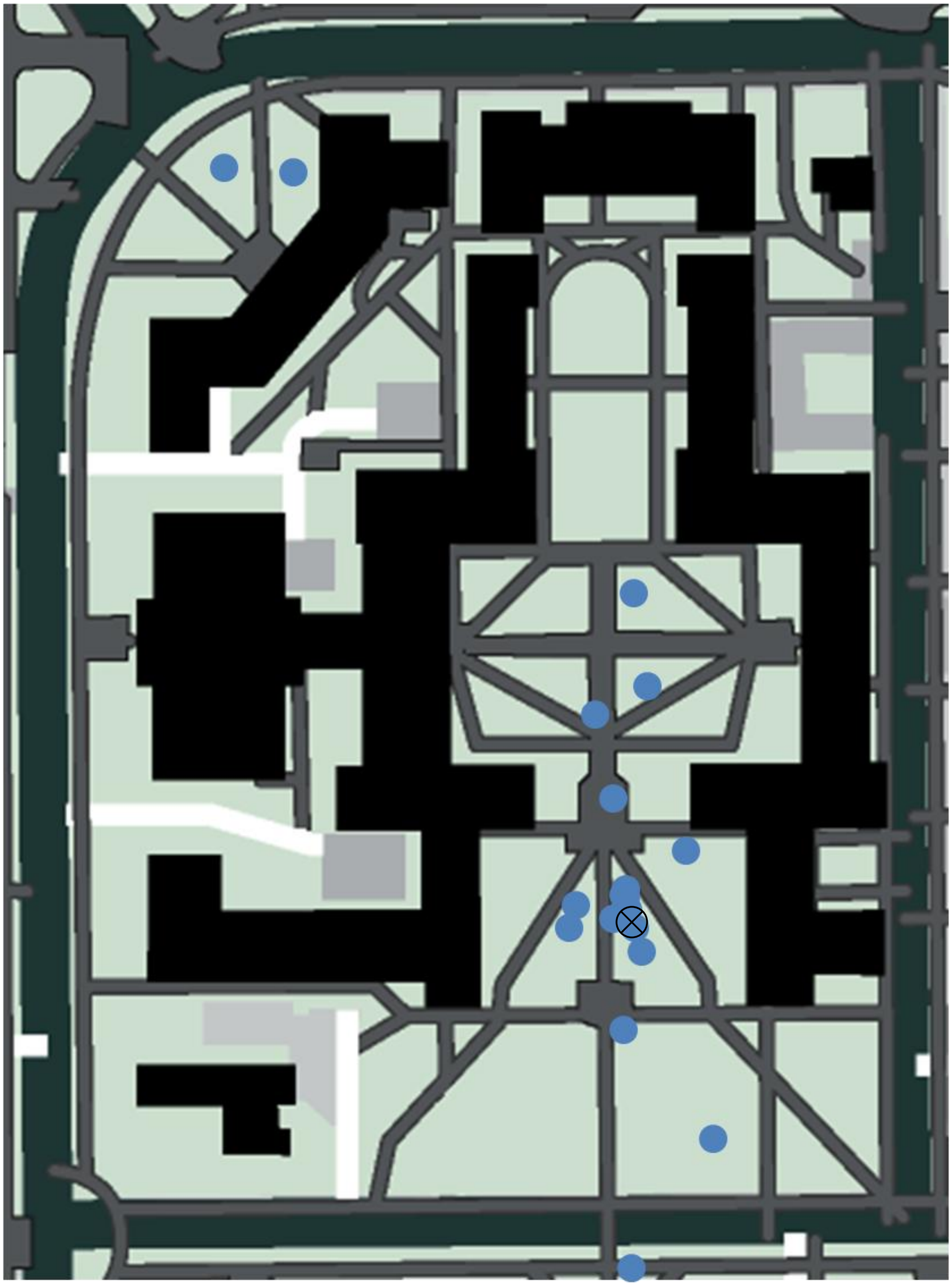


Figure 8.22. Composite map of answers to the black flag for boys.

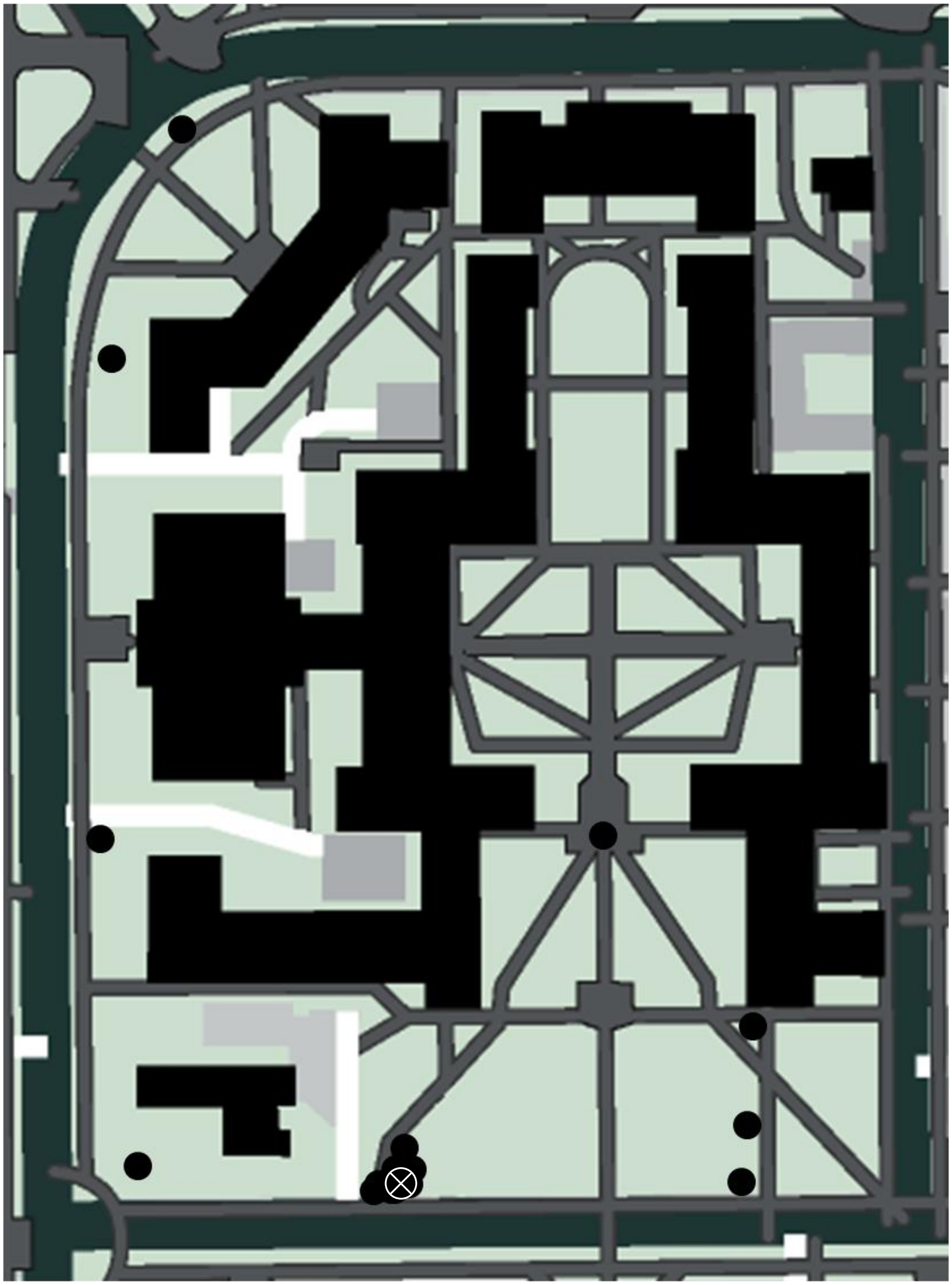


Figure 8.23. Composite map of answers to the white flag for boys.

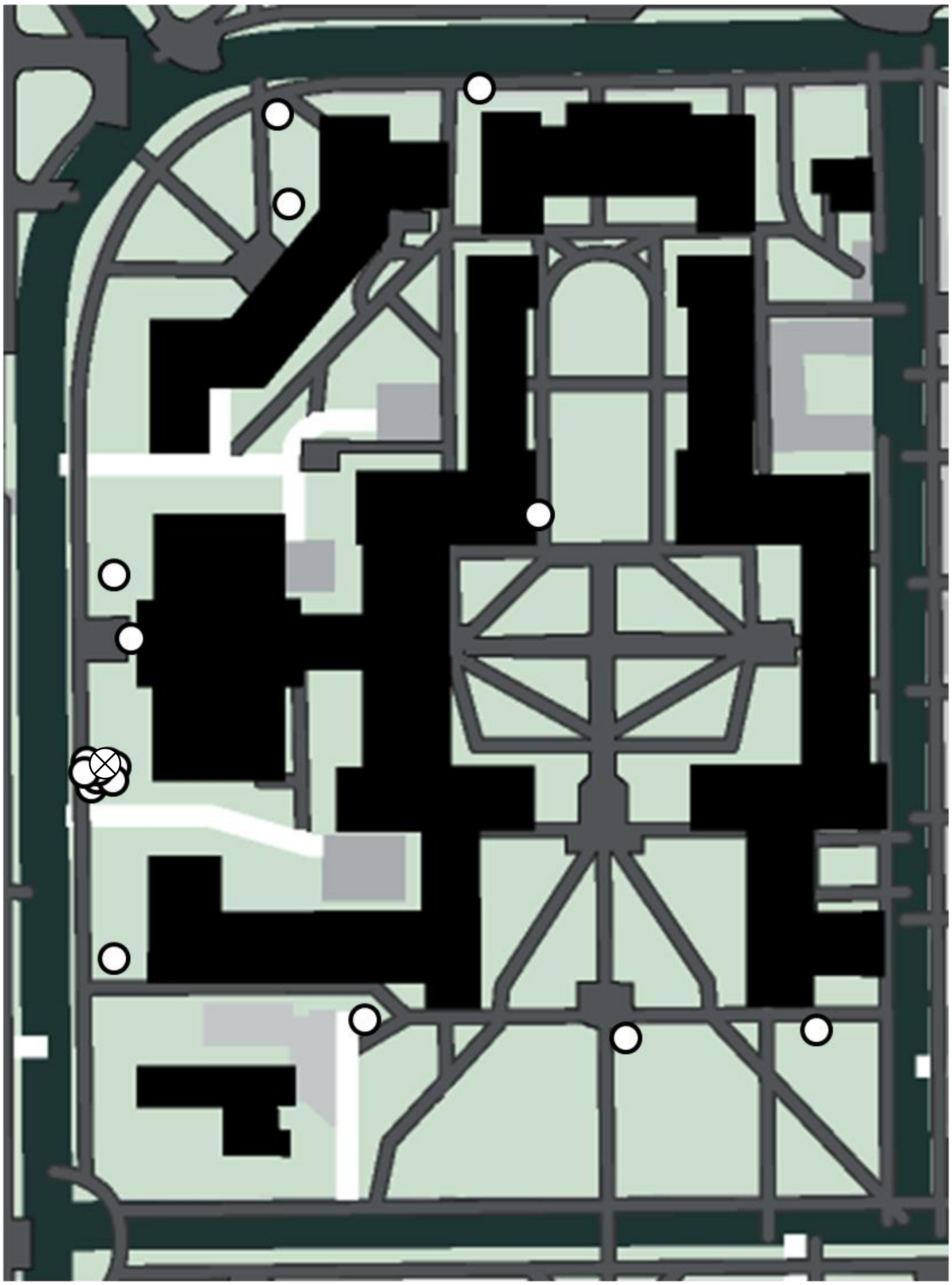


Figure 8.24. Composite map of answers to the yellow flag for boys.

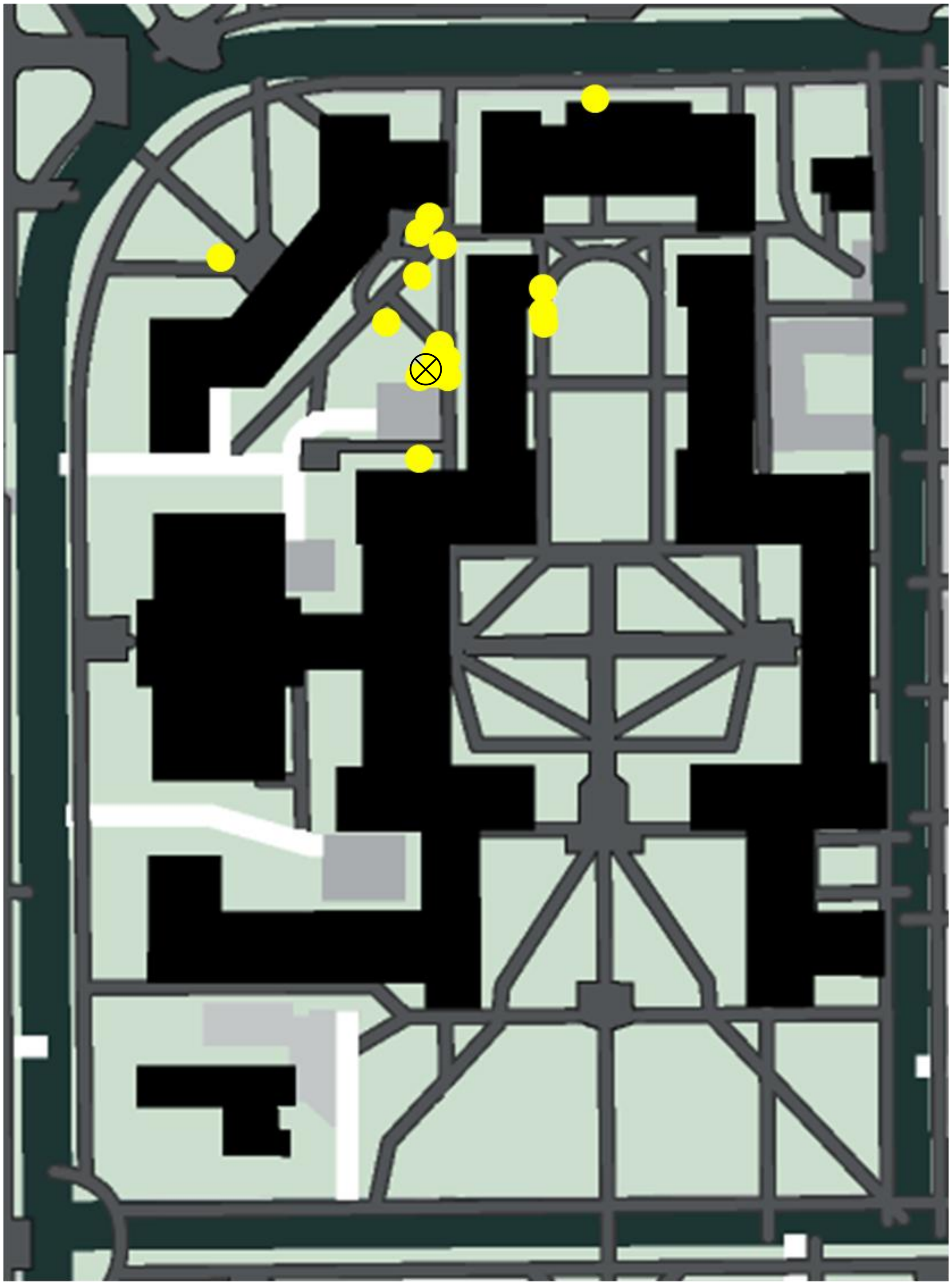


Figure 8.25. Composite map of answers to the red flag for girls.

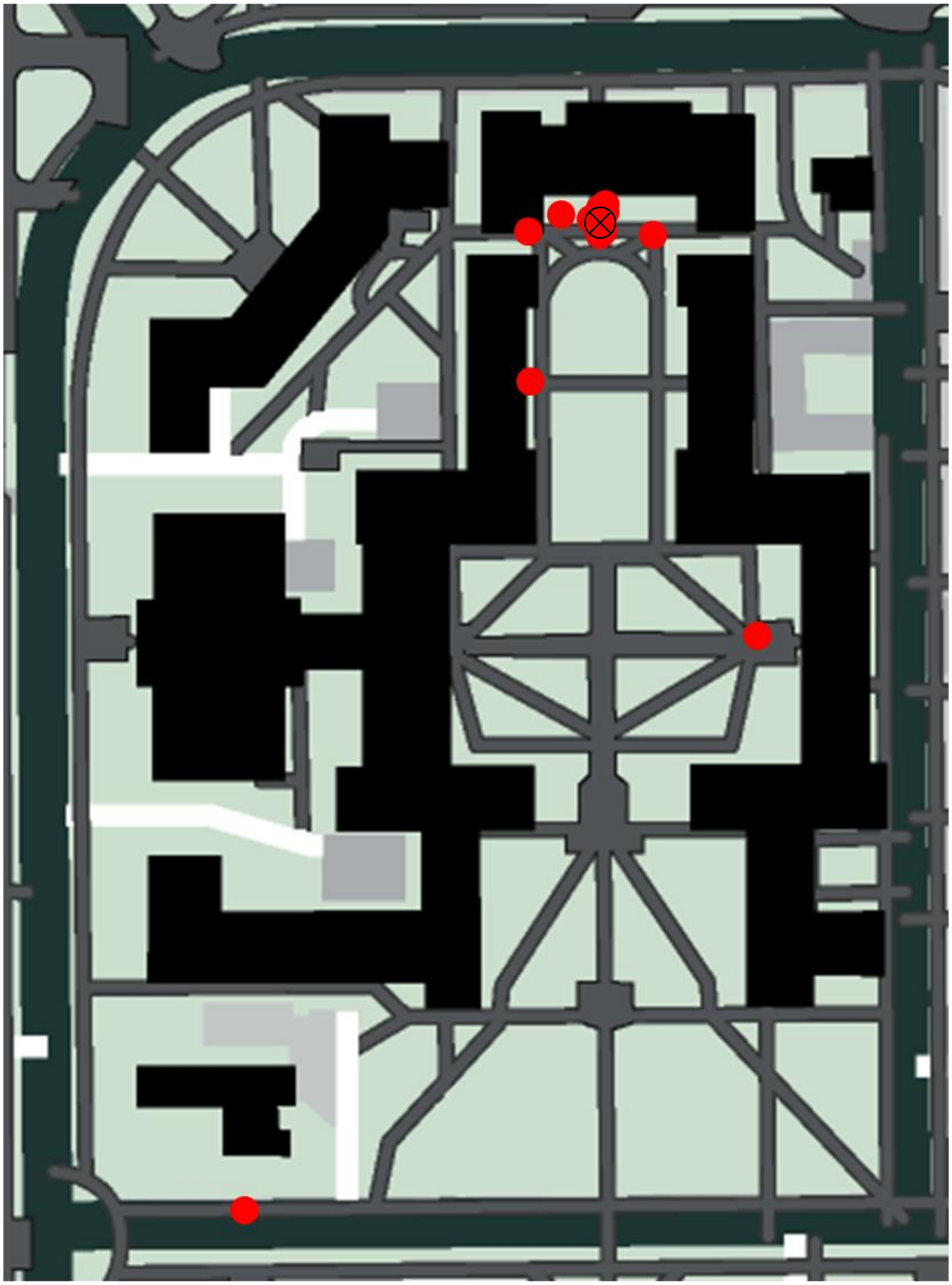


Figure 8.26. Composite map of answers to the green flag for girls.

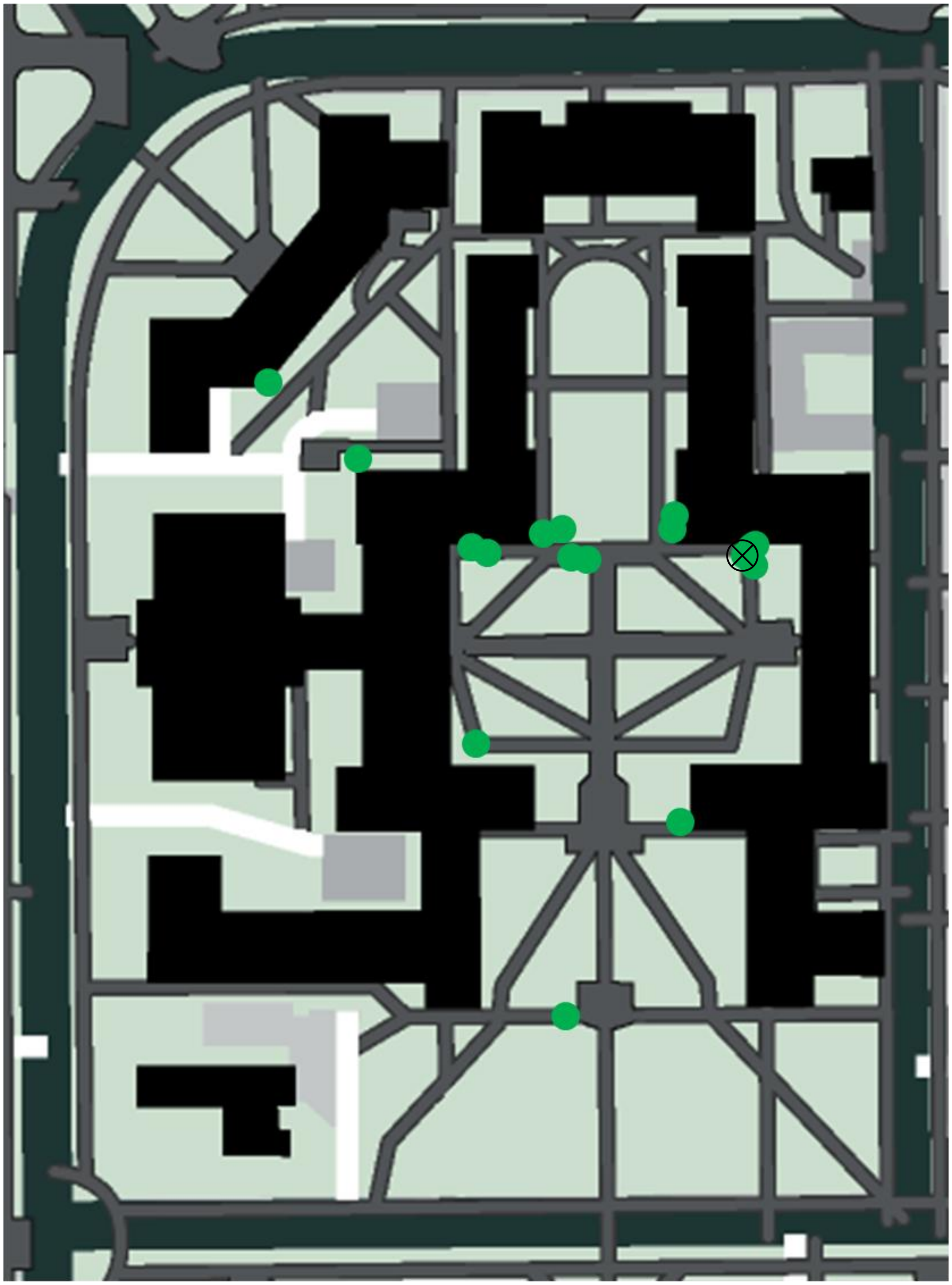


Figure 8.27. Composite map of answers to the blue flag for girls.

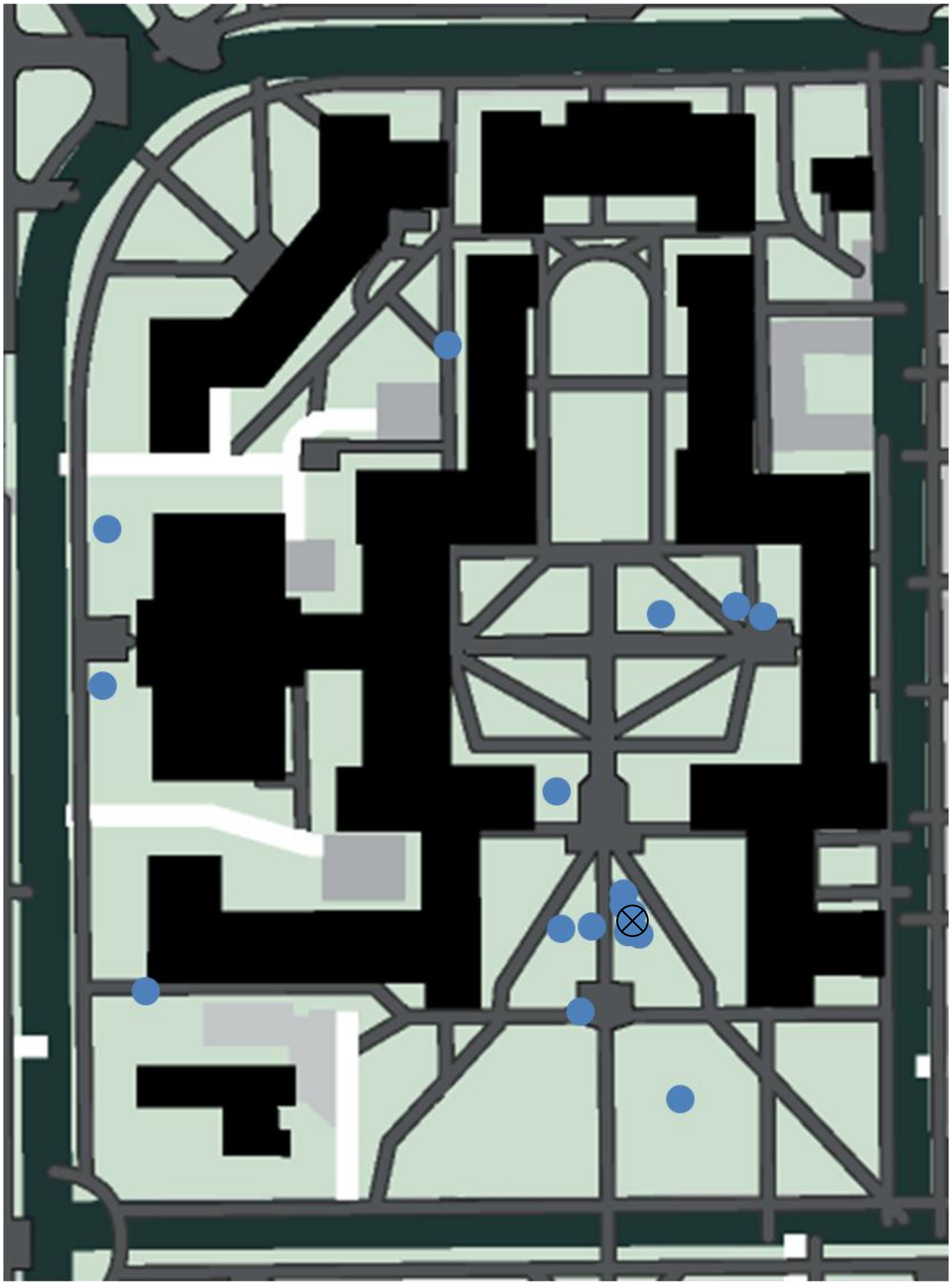


Figure 8.28. Composite map of answers to the black flag for girls.

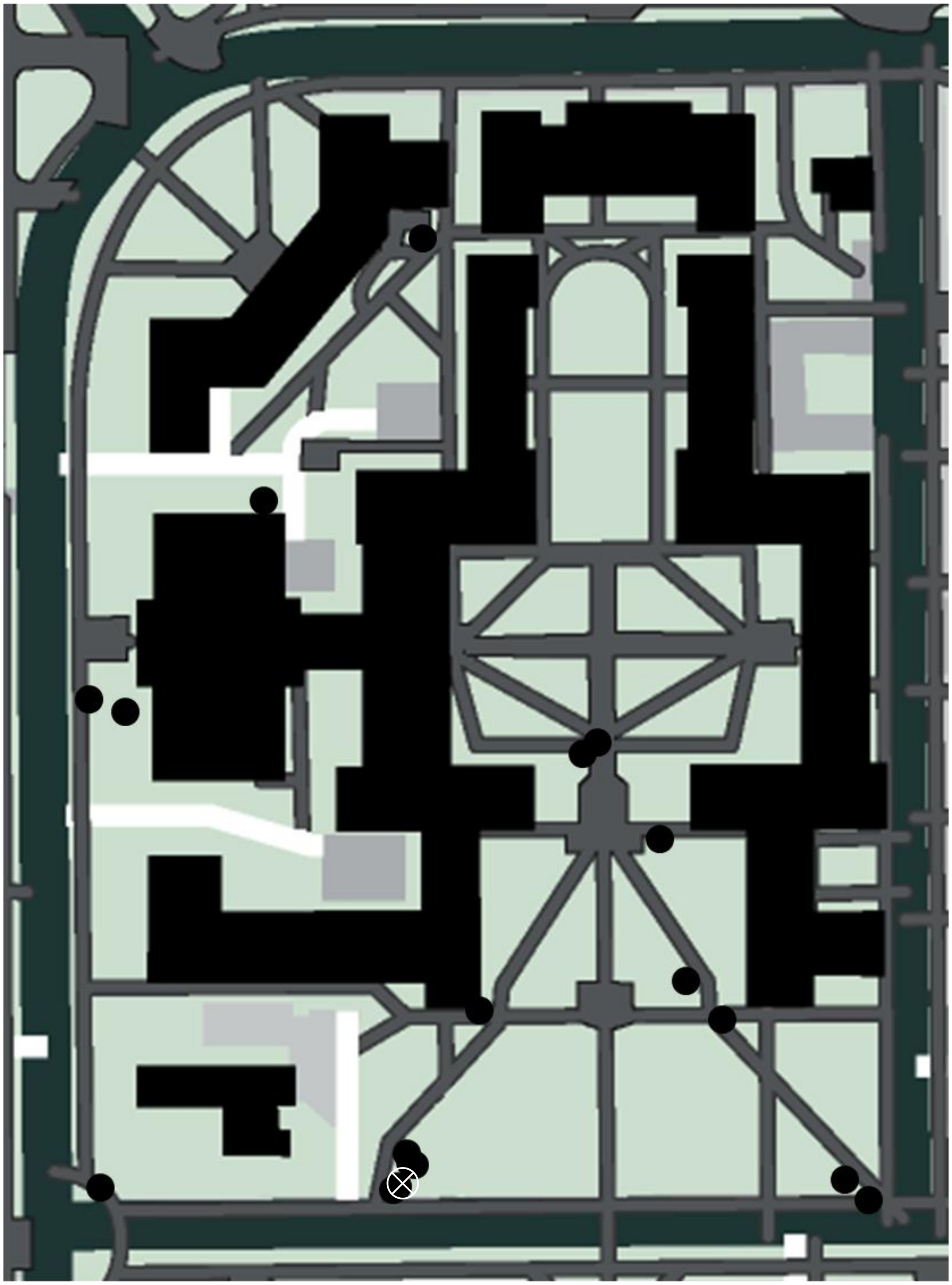


Figure 8.29. Composite map of answers to the white flag for girls.

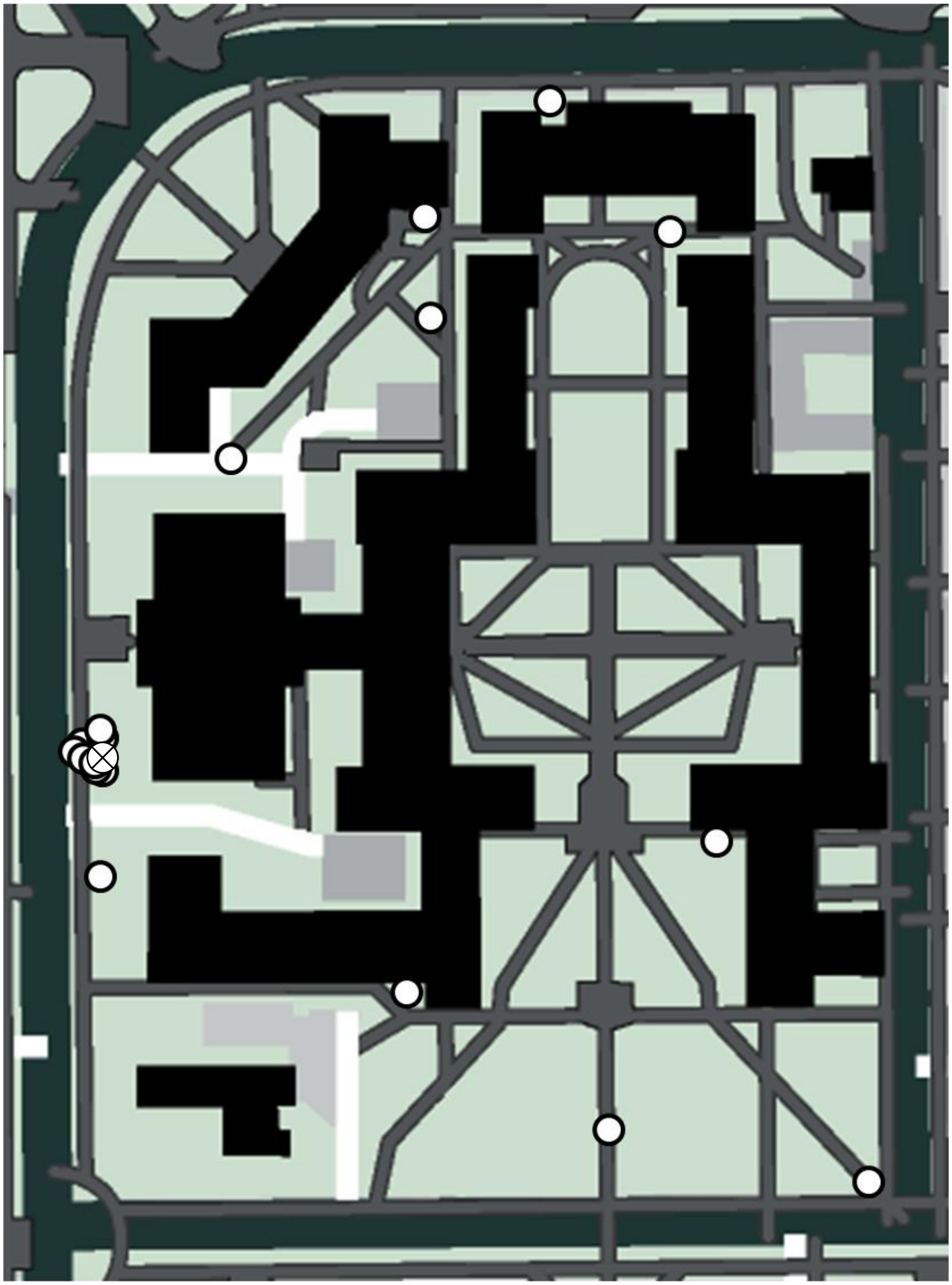


Figure 8.30. Composite map of answers to the yellow flag for girls.

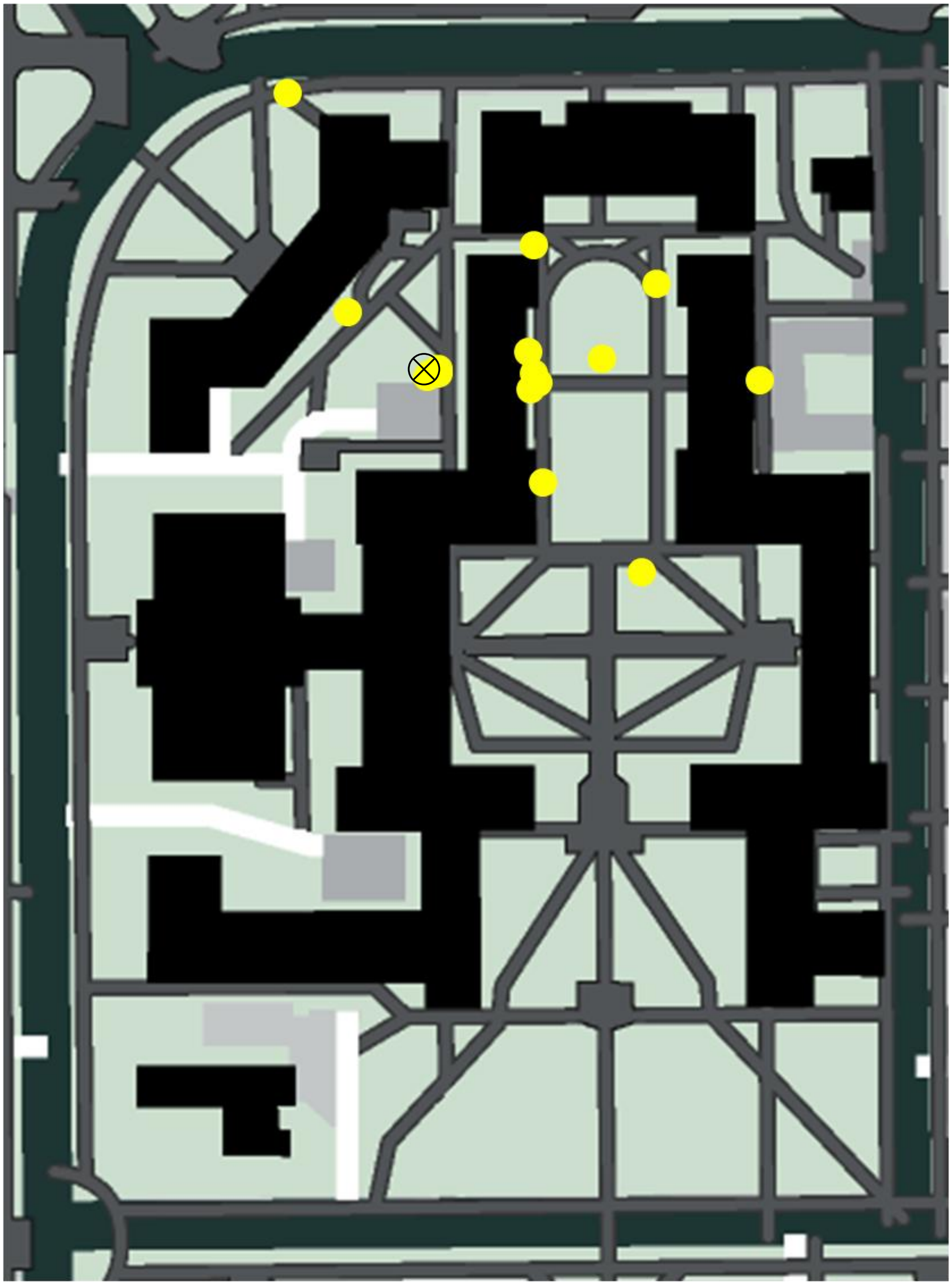


Figure 9. Mean DI by sex

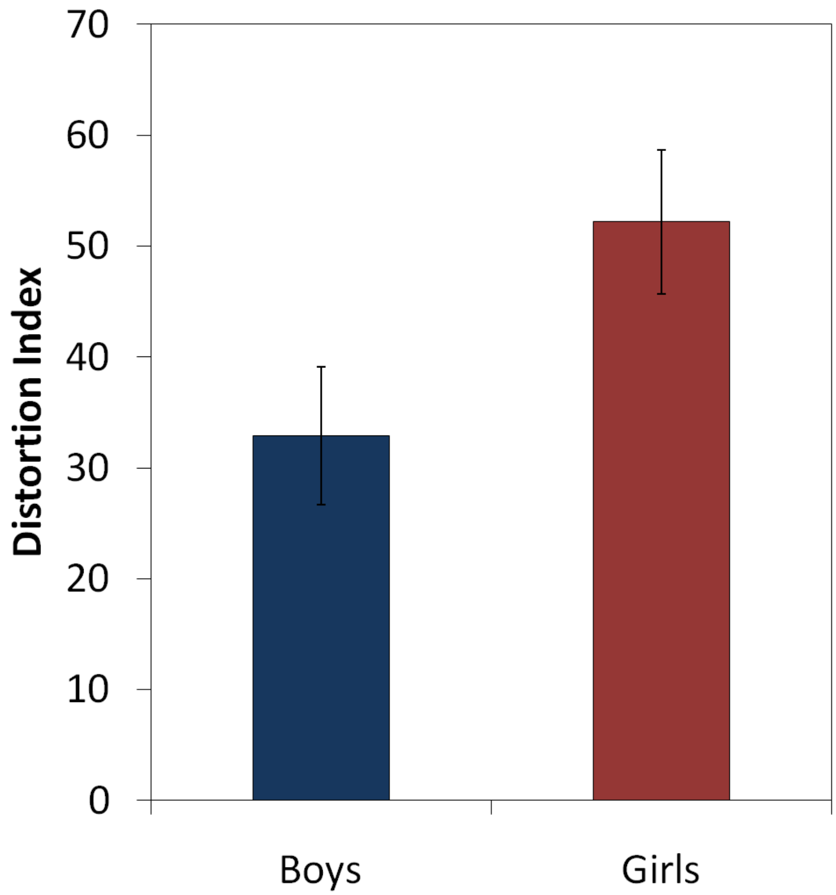


Figure 10. Mean DI by condition

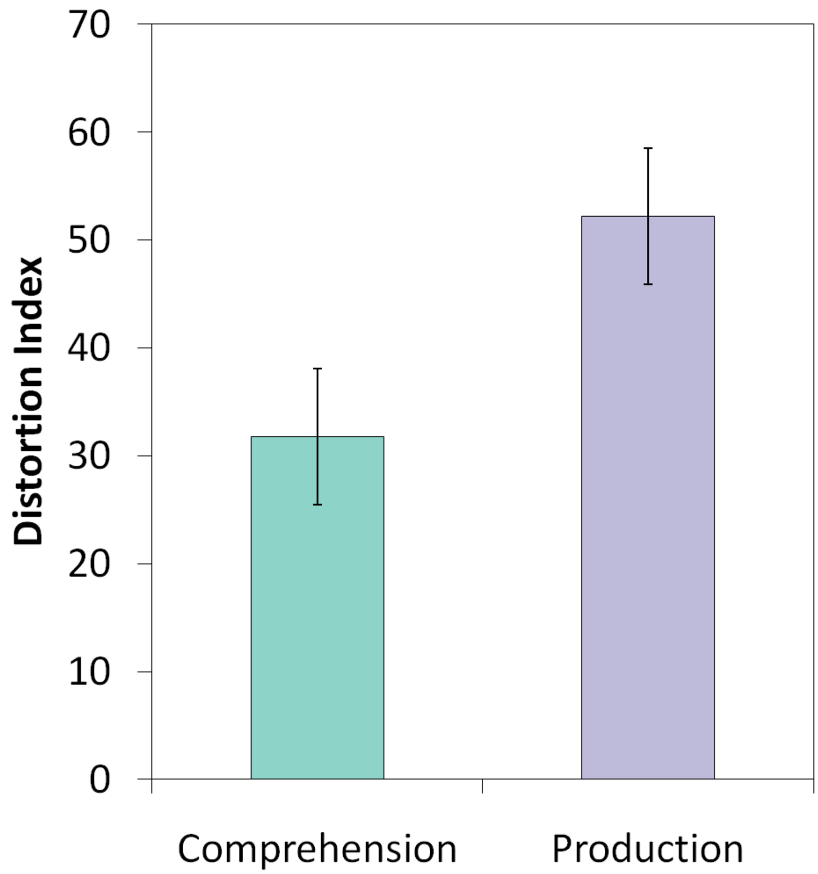


Figure 11.1. Illustration of one high-performing child's (female in production condition) responses with the correct and observed placements as well as the predicted estimate from the bidimensional regression. This predicted layout can be read similarly to a regression line. This child's bidimensional regression parameters were: DI = 3.0, scale = 0.99, and θ = 359.

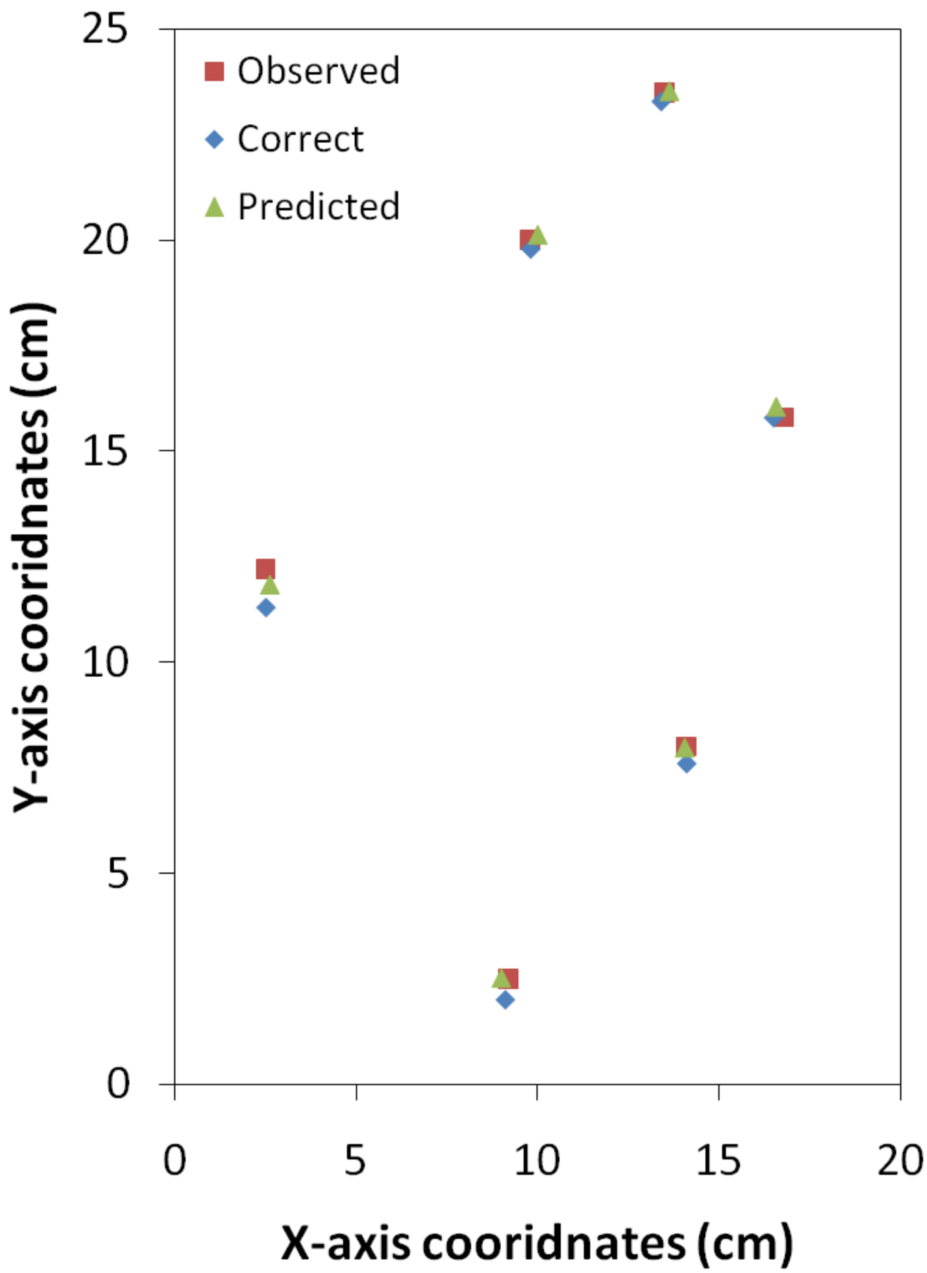


Figure 11.2. Illustration of one low-performing child's (boy in the production group) responses with the correct and observed placements as well as the predicted estimate from the bidimensional regression. This predicted layout can be read similarly to a regression line. This child's bidimensional regression parameters were: DI = 80.5, scale = 0.42, and θ = 341.1.

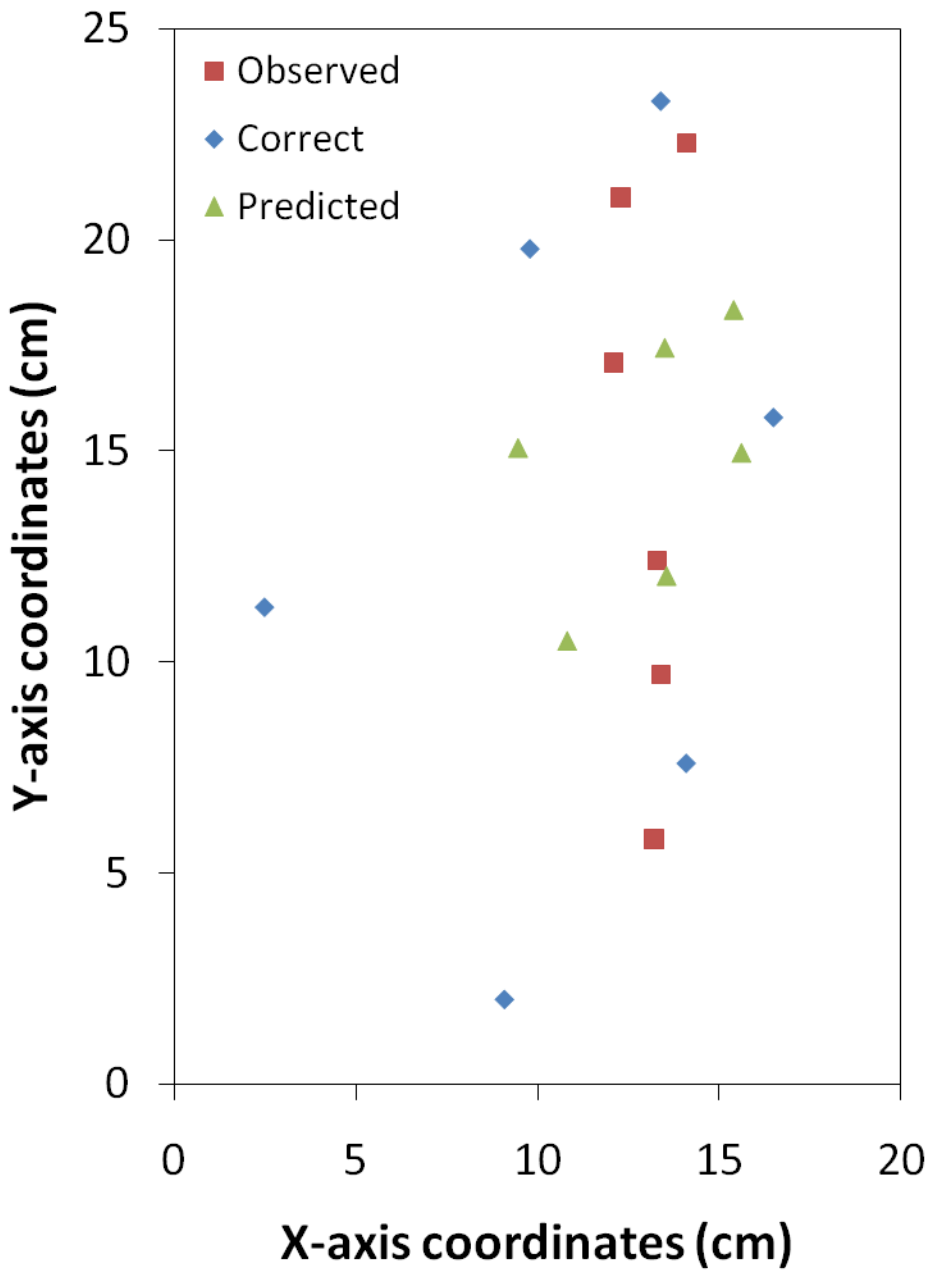


Figure 12.1. Rose diagrams illustrating distribution of responses for pointing location 1. Red arrow indicates correct answer, bin sizes are 15°, and each concentric circle represents 10% of the participants of the plotted group. Rose diagrams are aligned with the map orientation shown in previous figures such that the top of the rose diagrams corresponds with the top of the map.

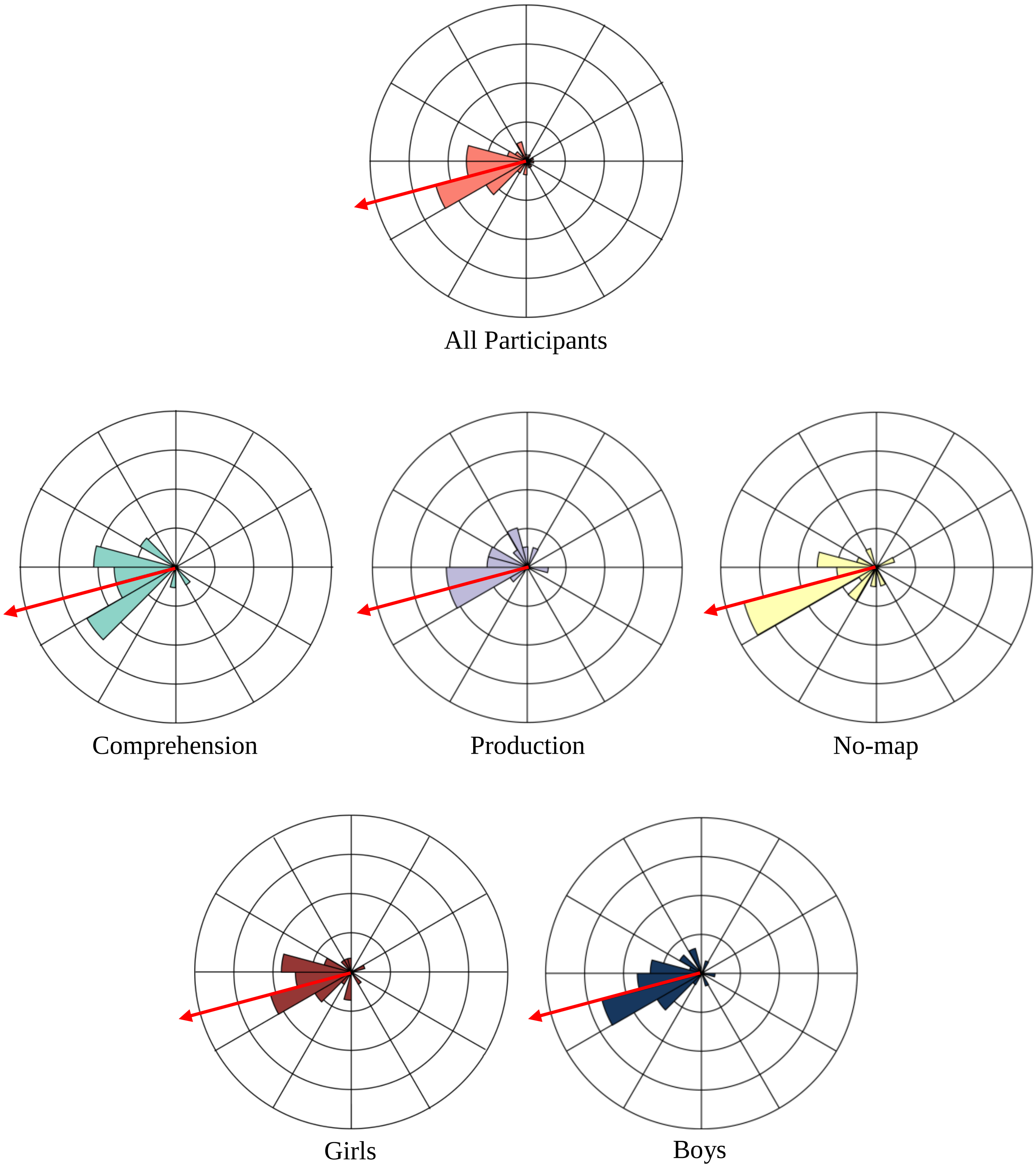


Figure 12.2. Rose diagrams illustrating distribution of responses for pointing location 2. Red arrow indicates correct answer, bin sizes are 15°, and each concentric circle represents 10% of the participants of the plotted group. Rose diagrams are aligned with the map orientation shown in previous figures such that the top of the rose diagrams corresponds with the top of the map.

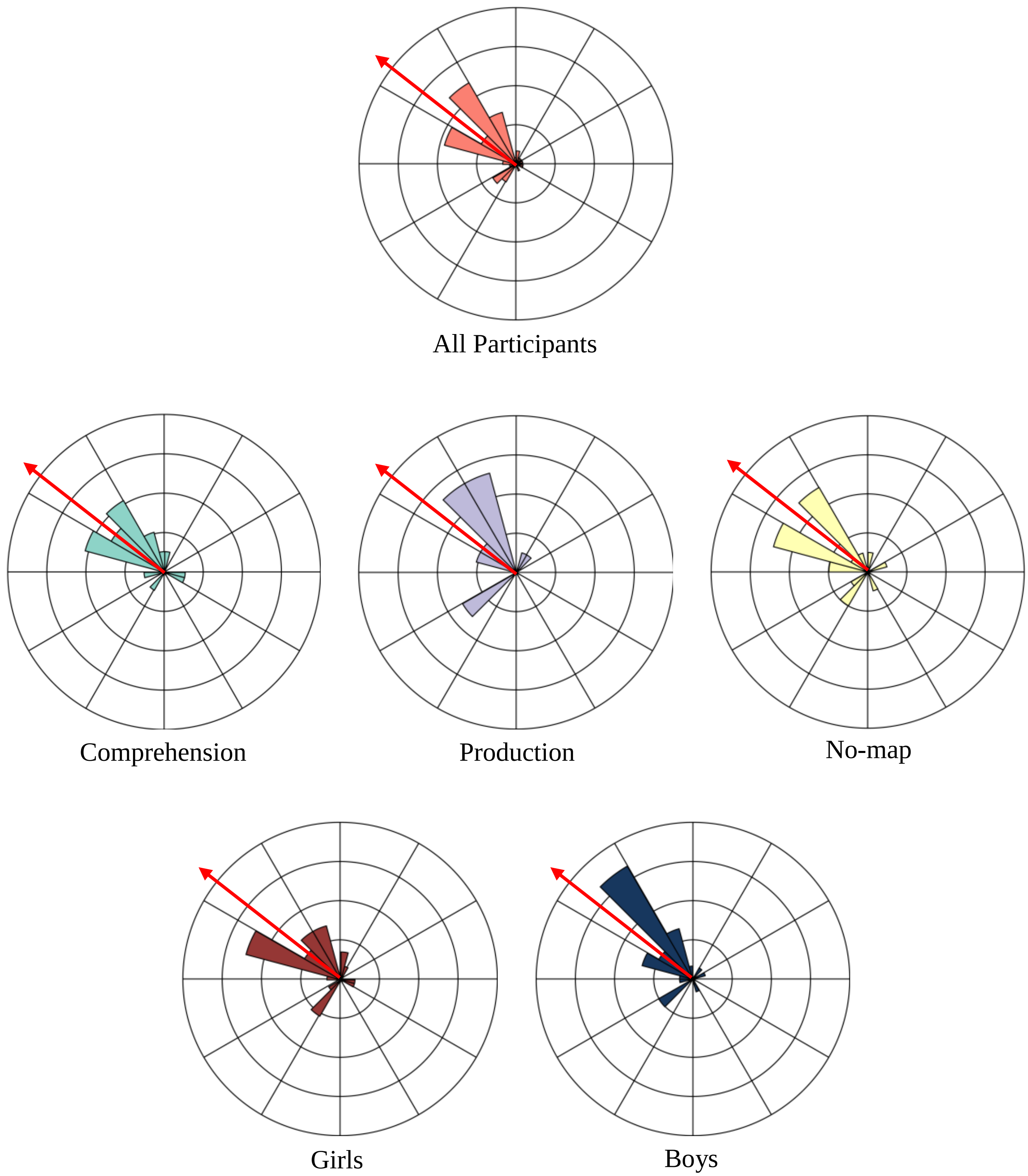


Figure 12.3. Rose diagrams illustrating distribution of responses for pointing location 3. Red arrow indicates correct answer, bin sizes are 15°, and each concentric circle represents 10% of the participants of the plotted group. Rose diagrams are aligned with the map orientation shown in previous figures such that the top of the rose diagrams corresponds with the top of the map.

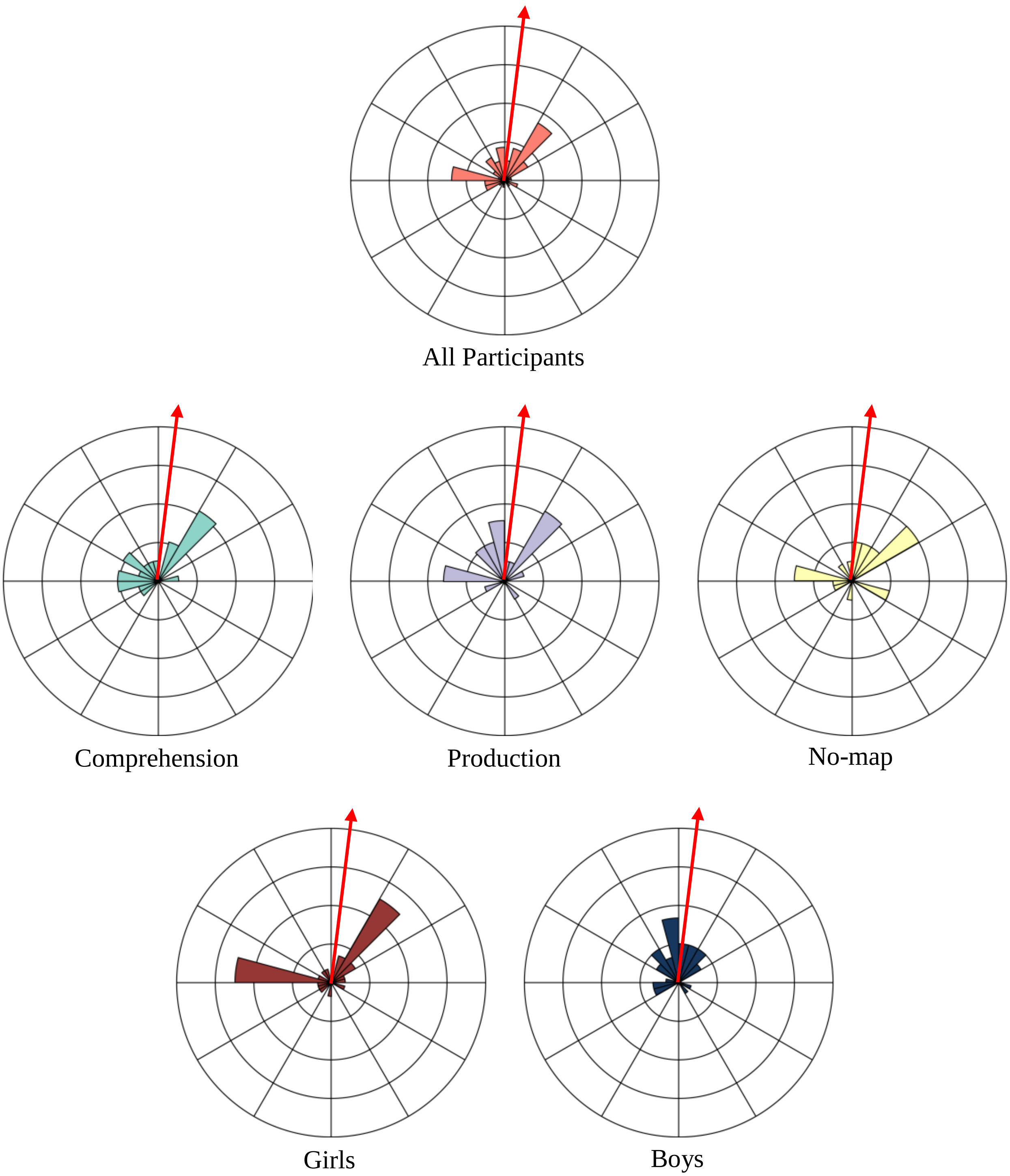


Figure 12.4. Rose diagrams illustrating distribution of responses for pointing location 4. Red arrow indicates correct answer, bin sizes are 15°, and each concentric circle represents 10% of the participants of the plotted group. Rose diagrams are aligned with the map orientation shown in previous figures such that the top of the rose diagrams corresponds with the top of the map.

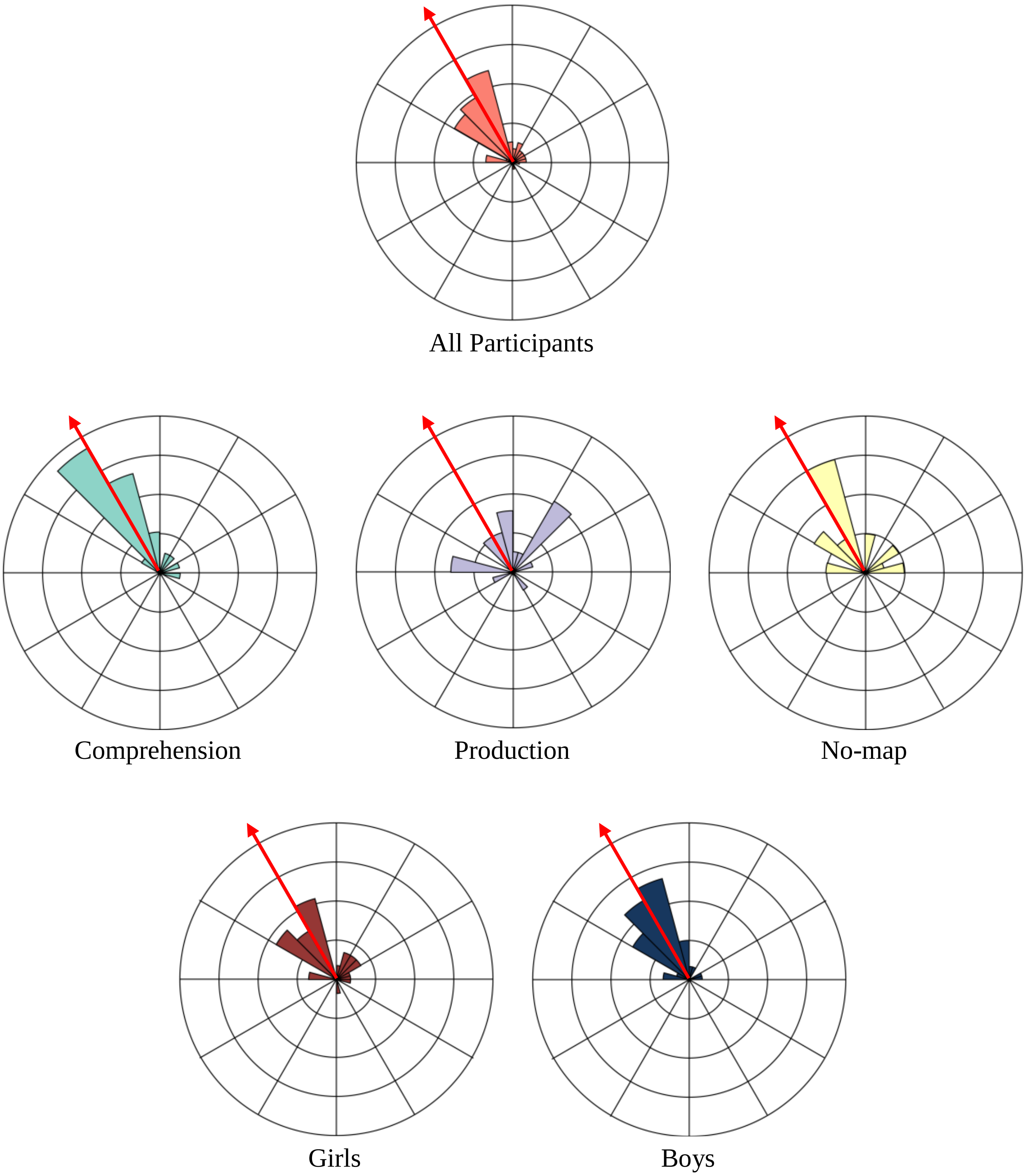


Figure 13. Mean route-to-target distance by sex

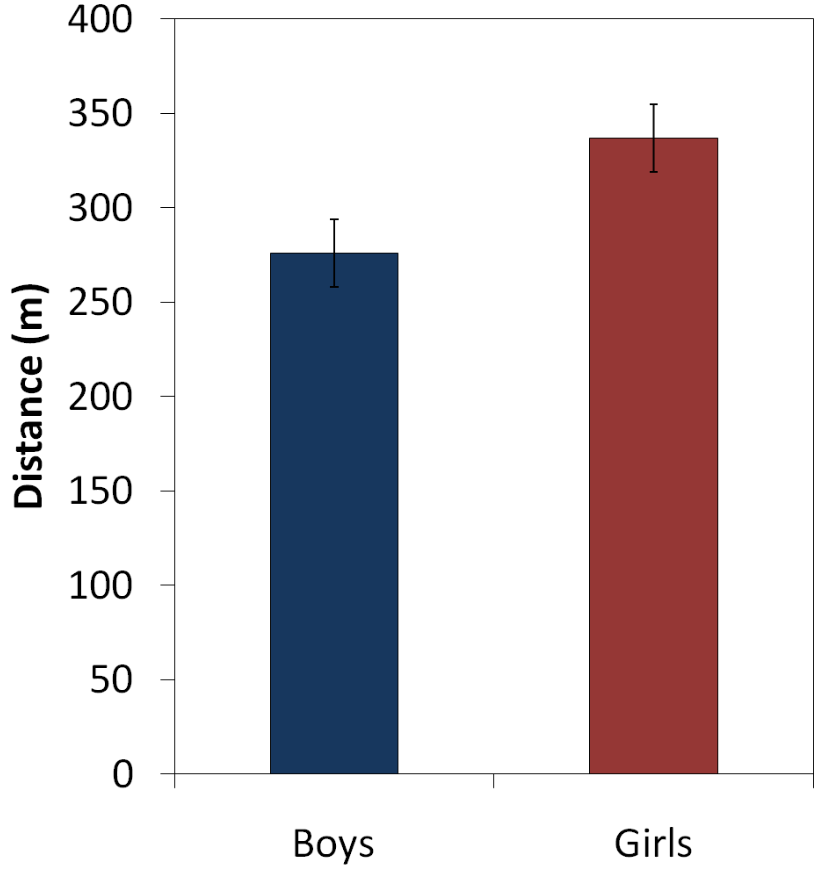


Figure 14. Distribution of route-to-target distances. The shortest possible distance a participant could travel was 190m.

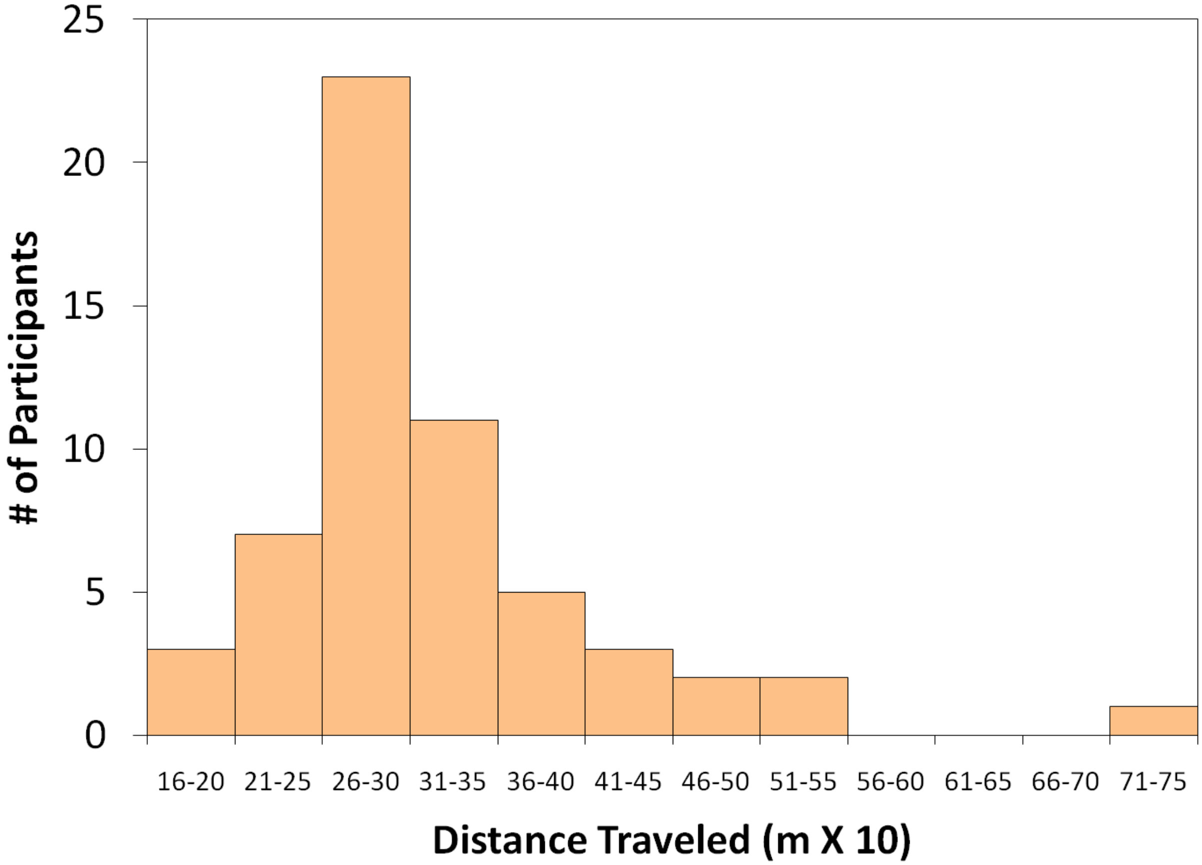


Figure 15. Mean distanced traveled to complete placement task by condition. The most efficient route possible to visit all correct flag locations was approximately 530m.

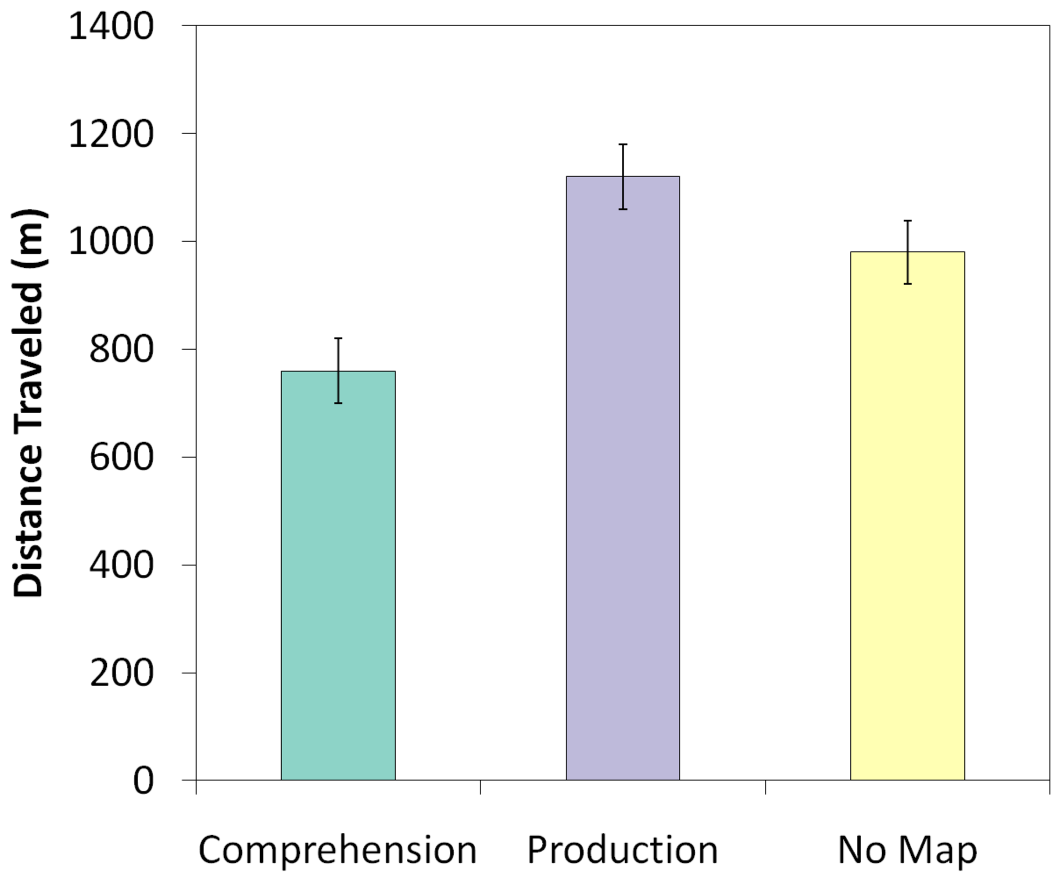


Figure 16. Distribution of distance traveled to complete the placement task. The most efficient route to visit all of the correct flag locations would be a path of 530m. The comprehension group had 3 children travel shorter distances than this most efficient route because they did not place all of the flags correctly.

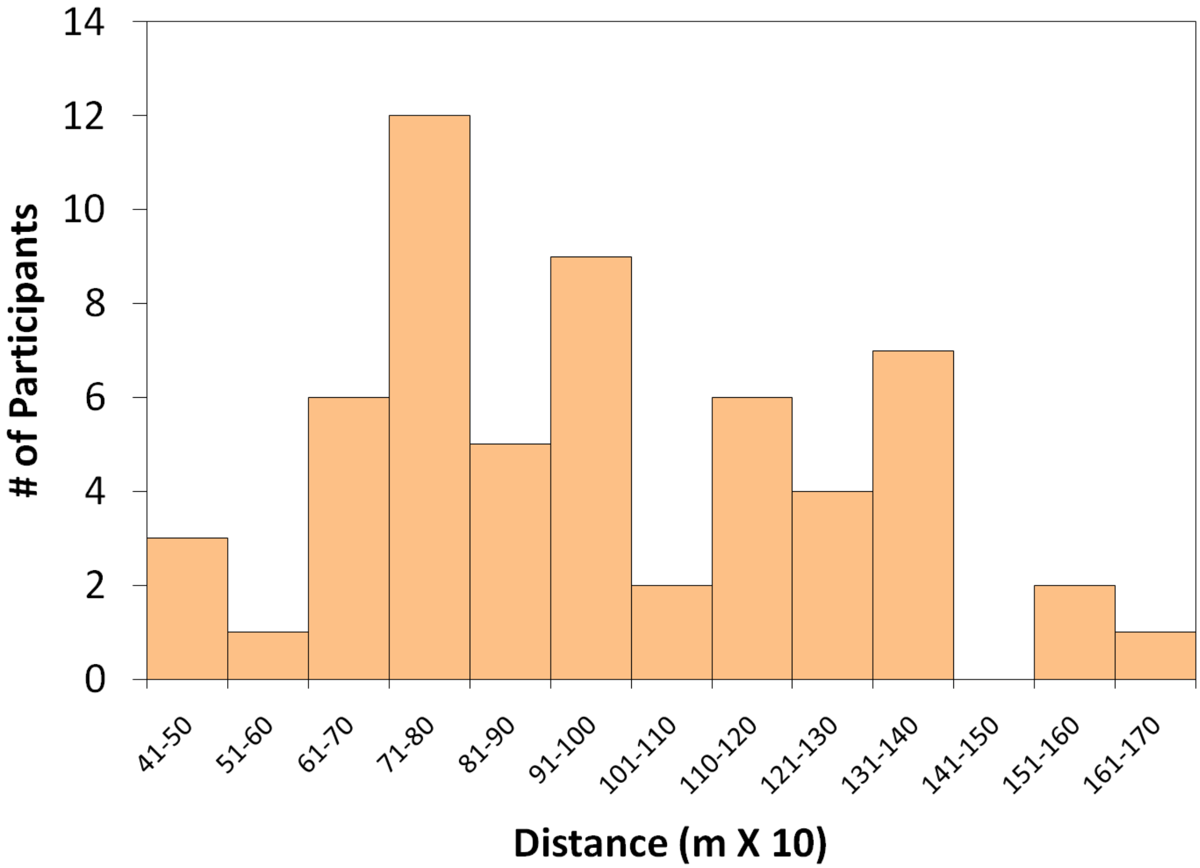


Figure 17.1. Network map for the comprehension condition showing linearly weighted paths between flag locations.

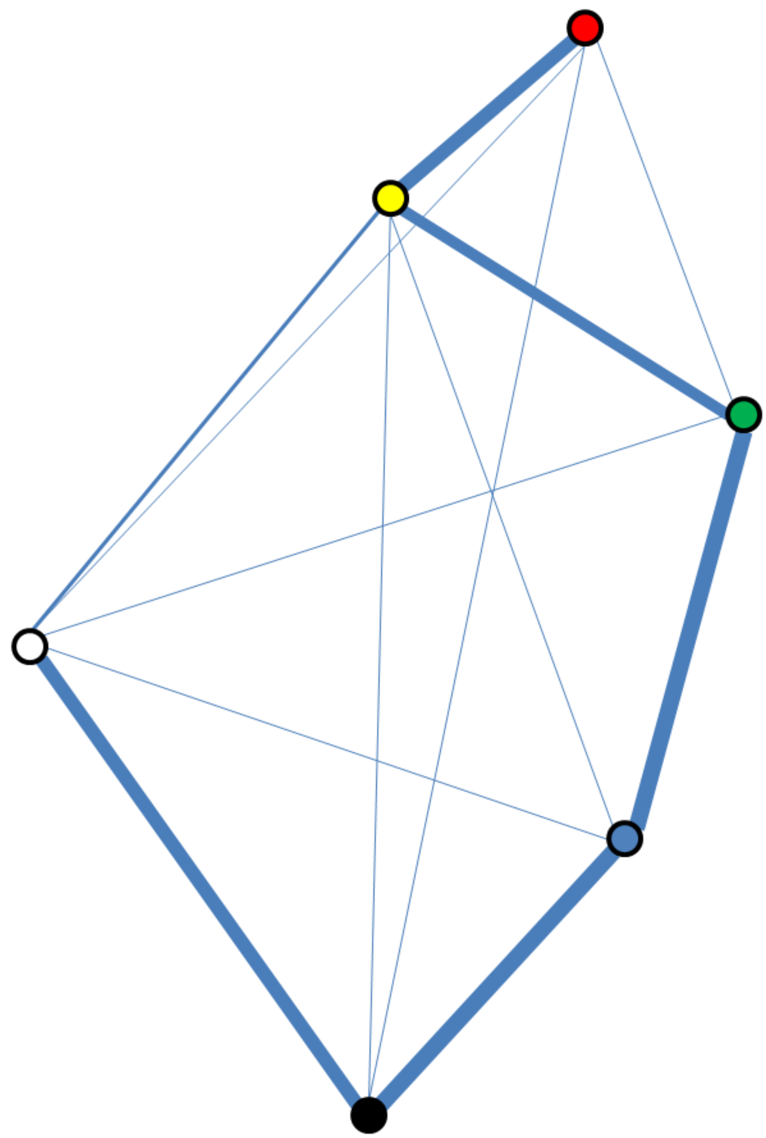


Figure 17.2. Network map for the production condition showing linearly weighted paths between flag locations.

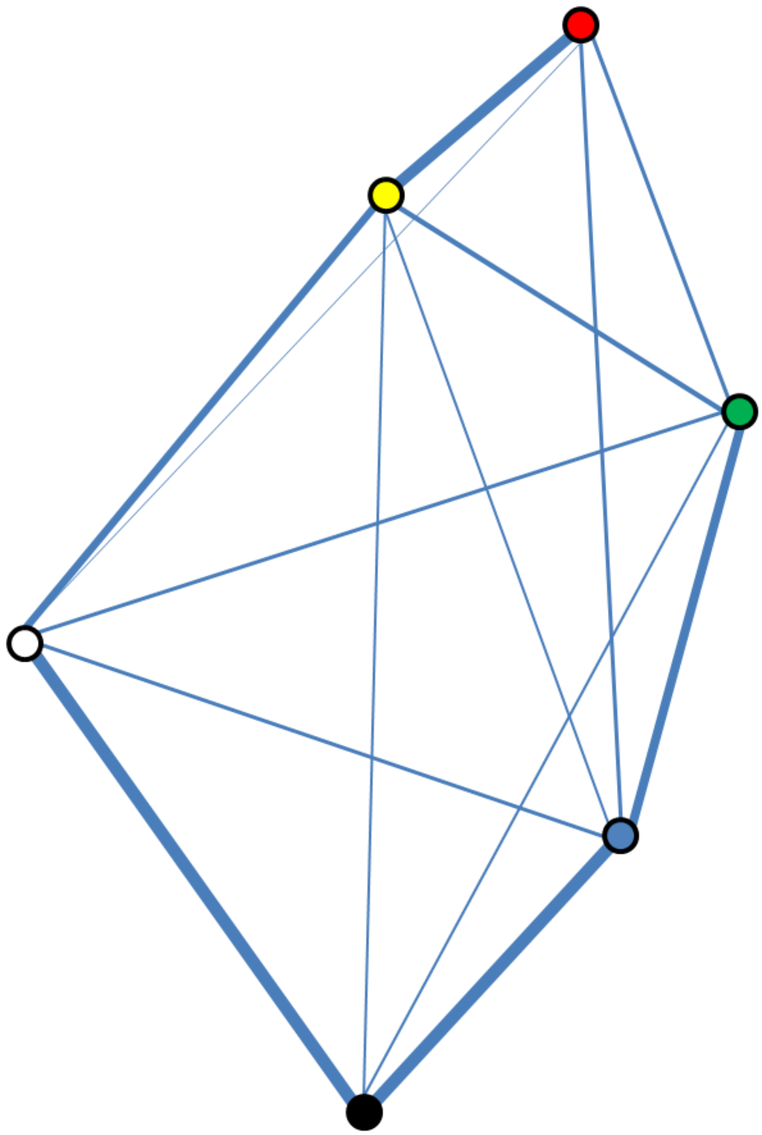


Figure 17.3. Network map for the no map condition showing linearly weighted paths between flag locations.

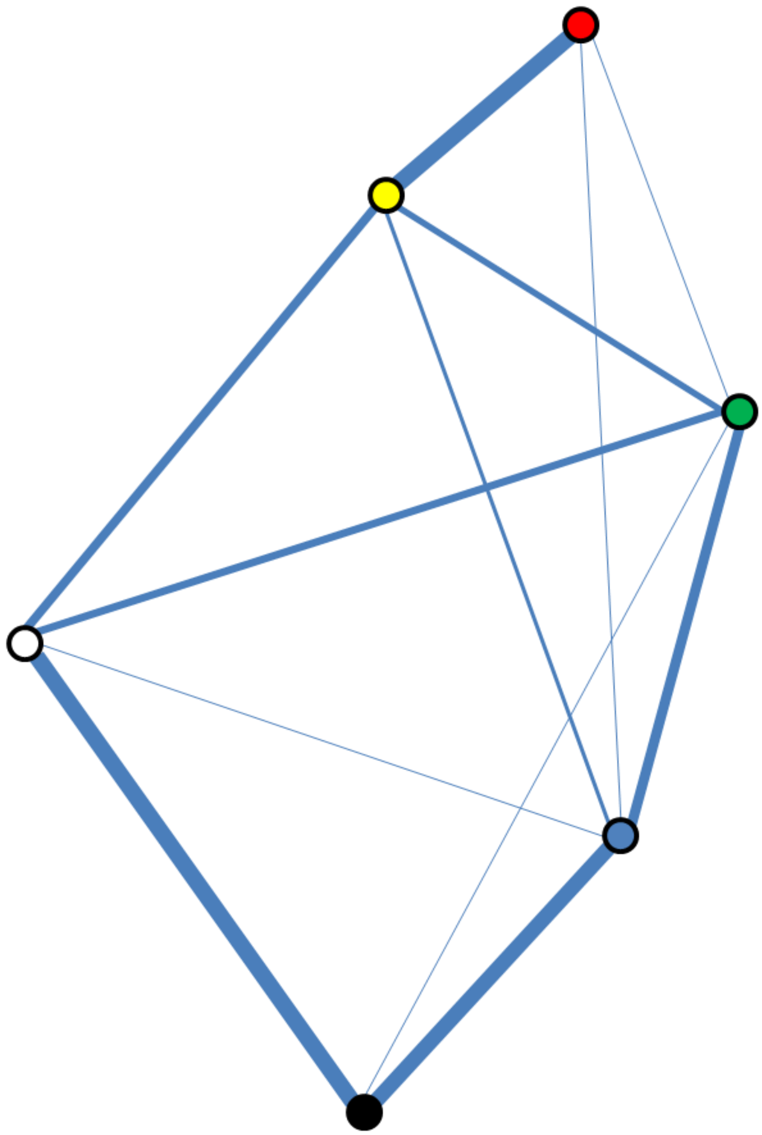


Figure 18. Mean task duration by condition

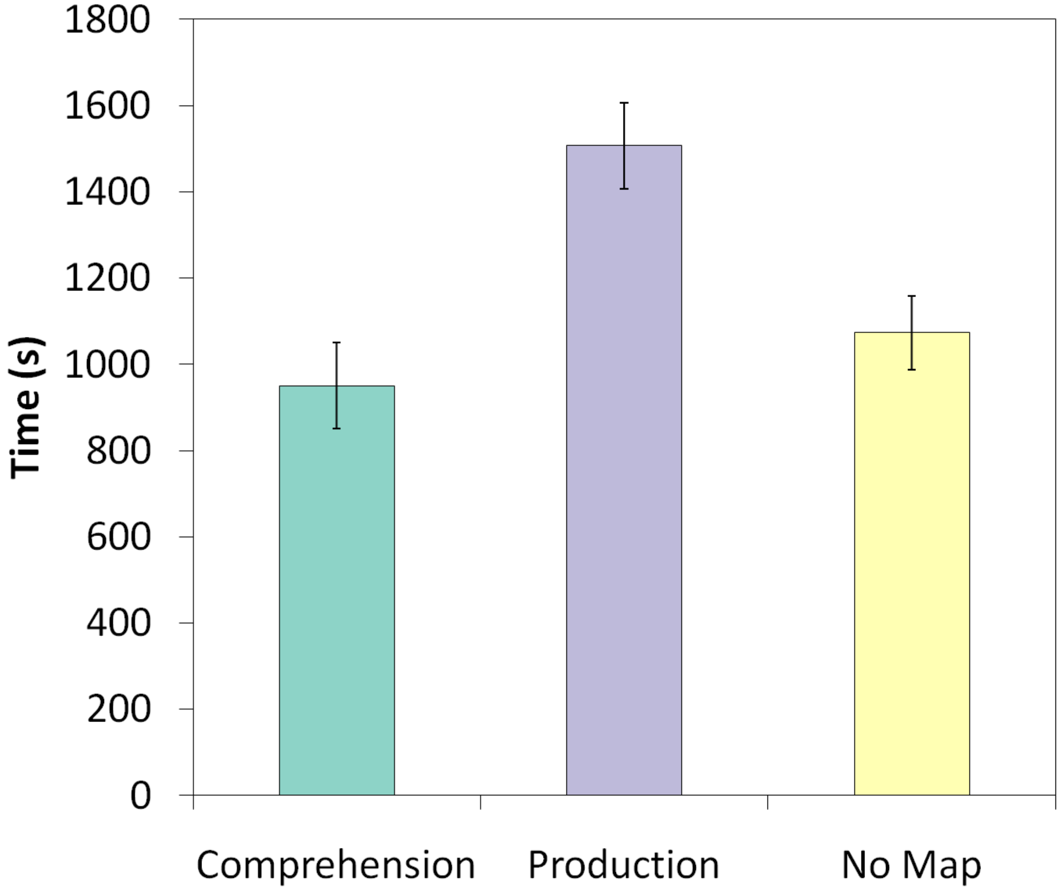


Figure 19. Mean proportion of time looking at map by condition and flag sequence. Flag sequence refers to the flags they visited first, second, etc. and not the color or position of the flags.

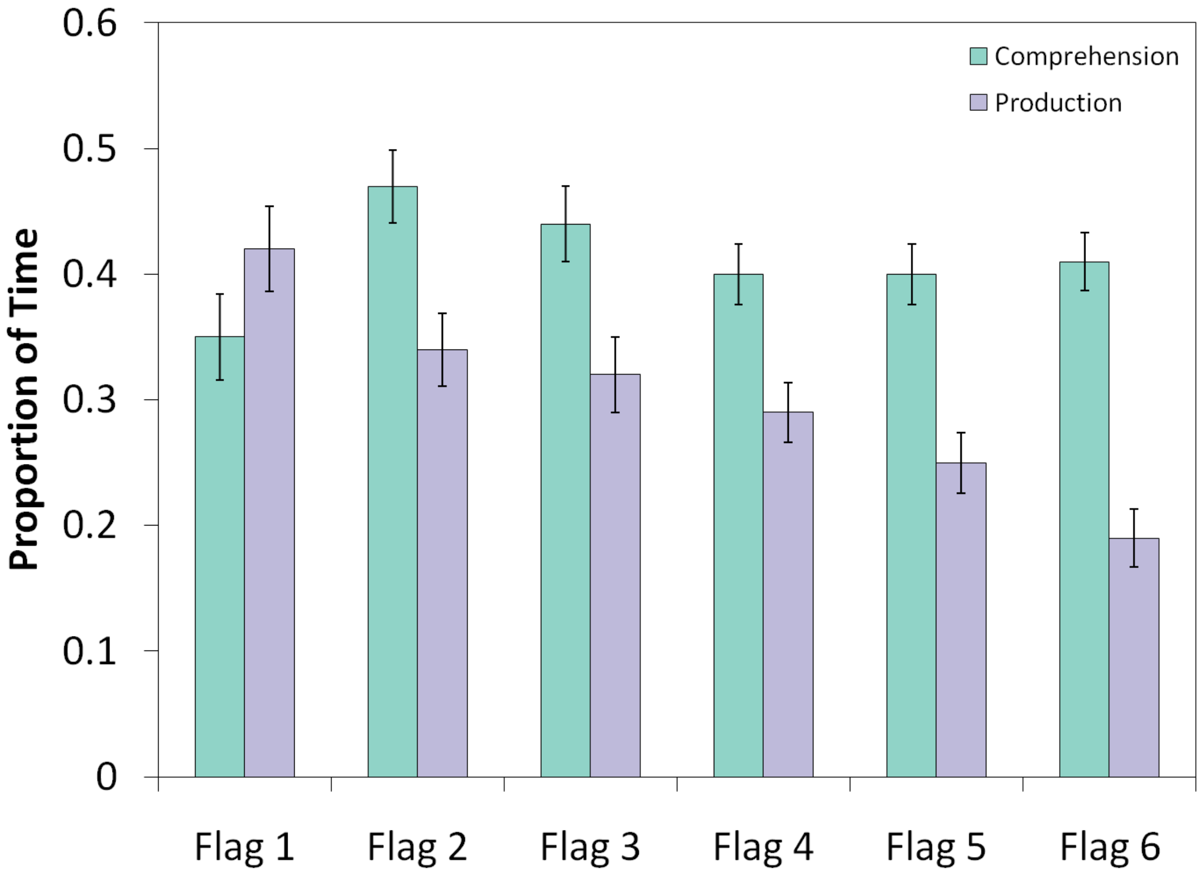


Figure 20. Mean proportion of time aligning the map with the environment by sex

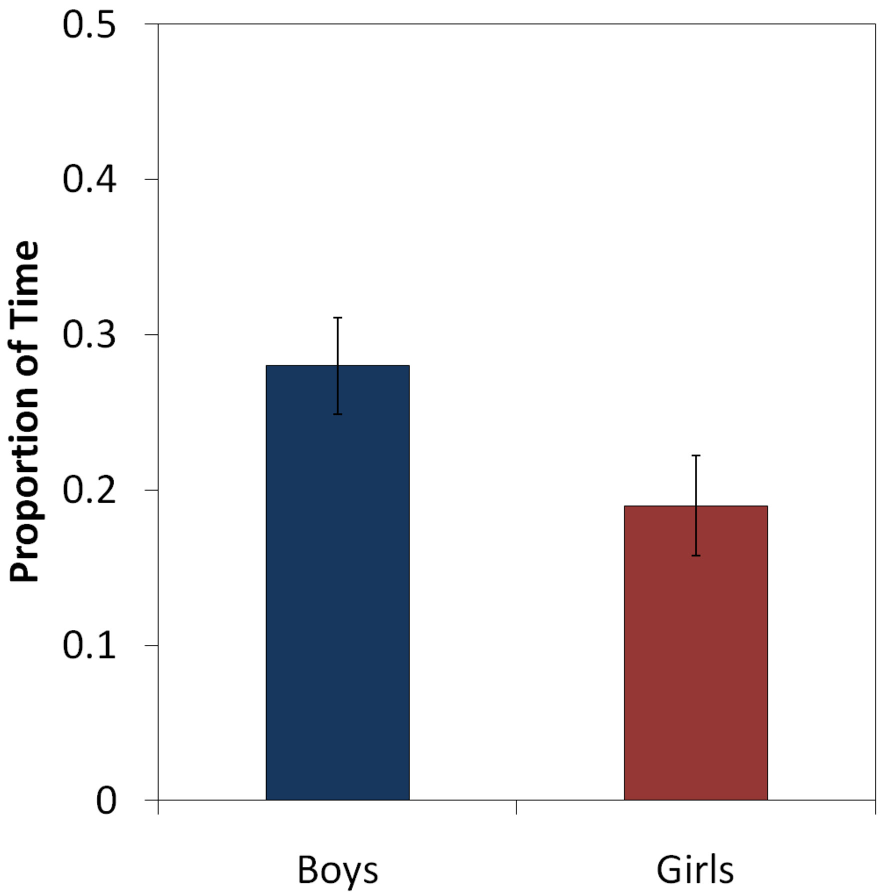


Figure 21. Mean proportion of time aligning the map with the environment by flag sequence. Flag sequence refers to the flags they visited first, second, etc. and not the color or position of the flags.

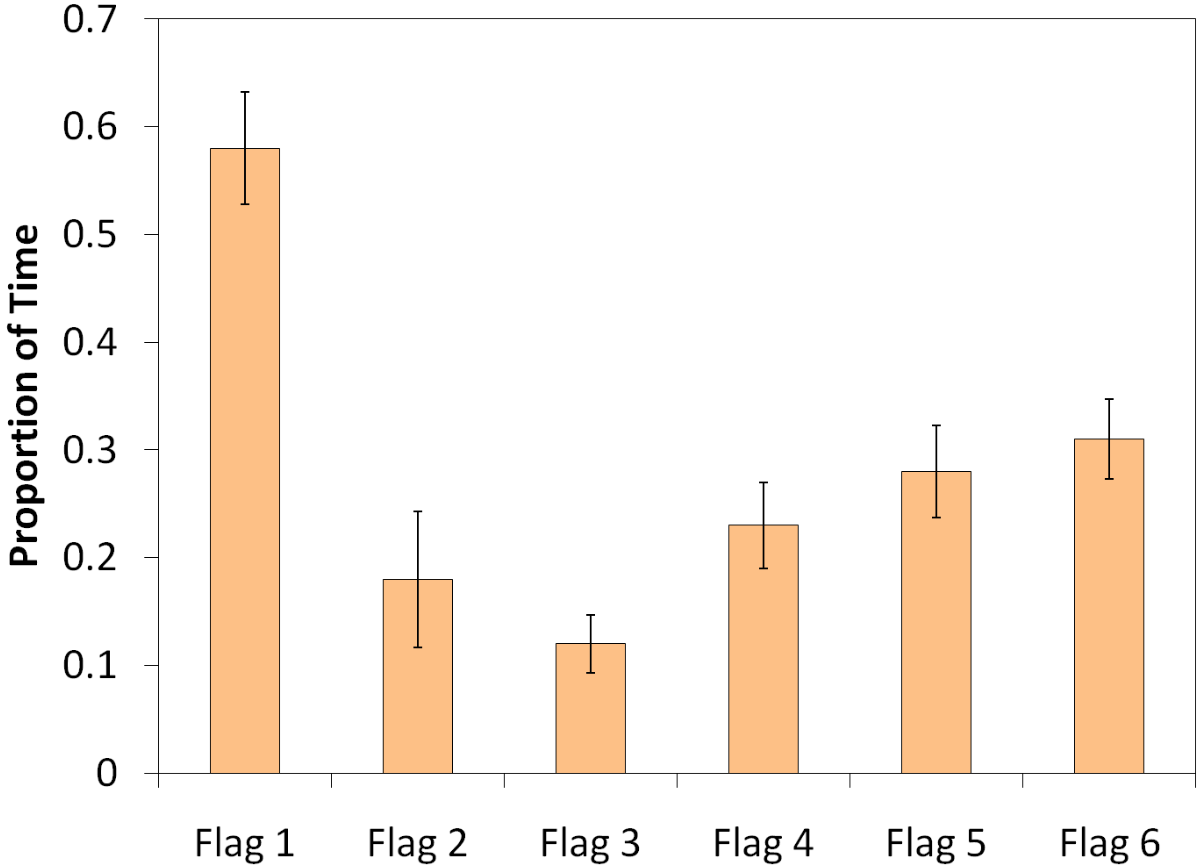


Figure 22. Mean proportion of time looking at the map while it was aligned with the environment by flag sequence. Flag sequence refers to the flags they visited first, second, etc. and not the color or position of the flags.

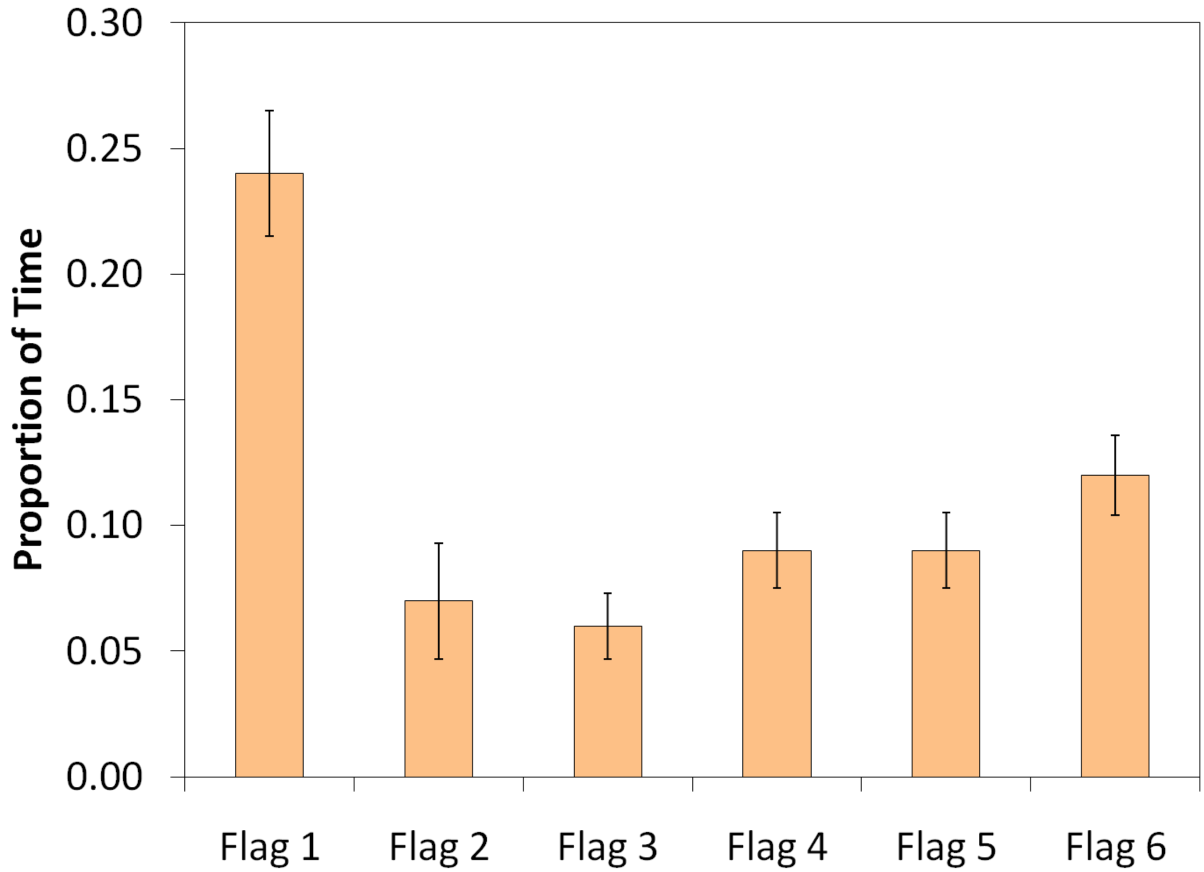


Figure 23. Mean proportion of time looking at the map while it was aligned with the environment by sex

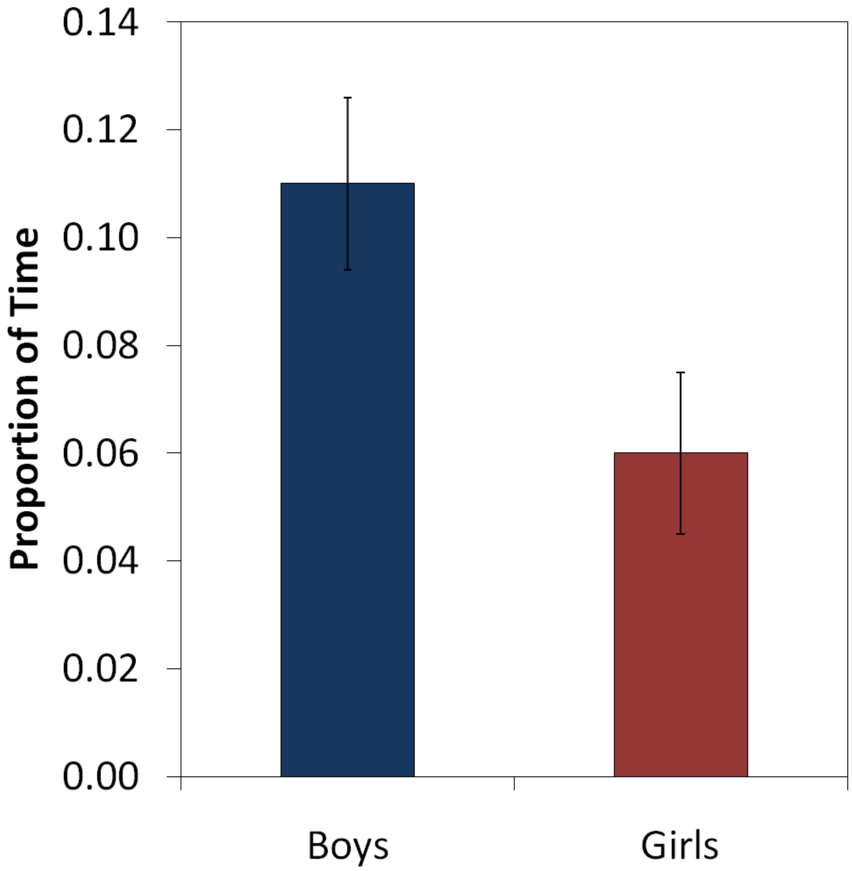


Figure 24. Mean proportion of time looking at the map while it was aligned with the environment by condition

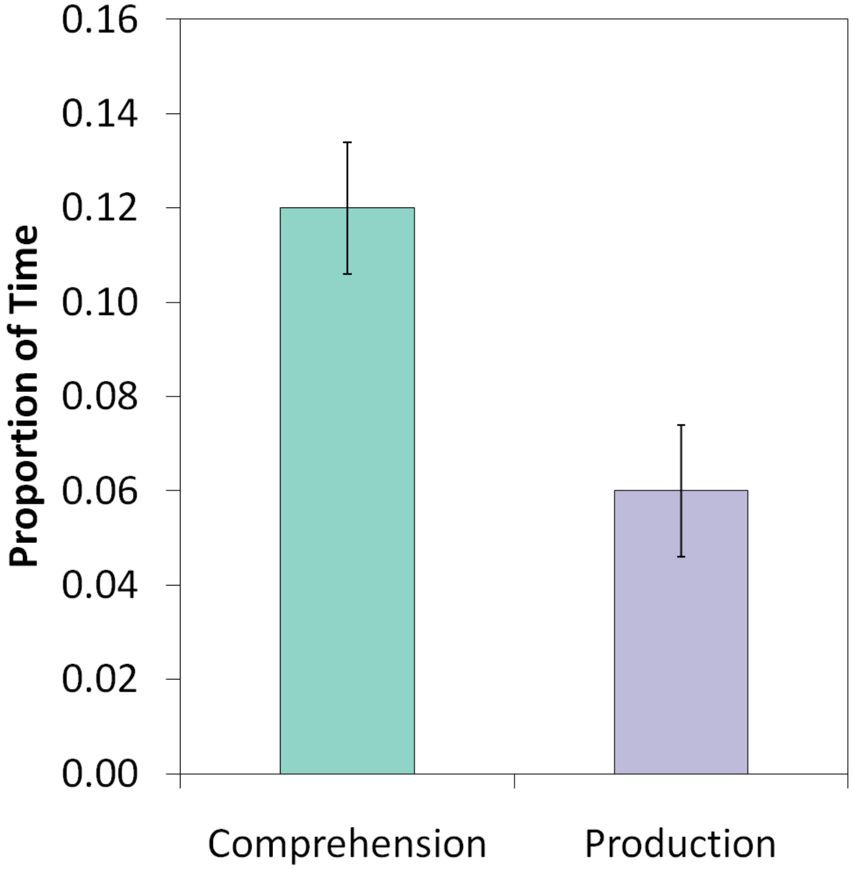


Figure 25. Mean frequency of map turns by flag sequence. Flag sequence refers to the flags they visited first, second, etc. and not the color or position of the flags.

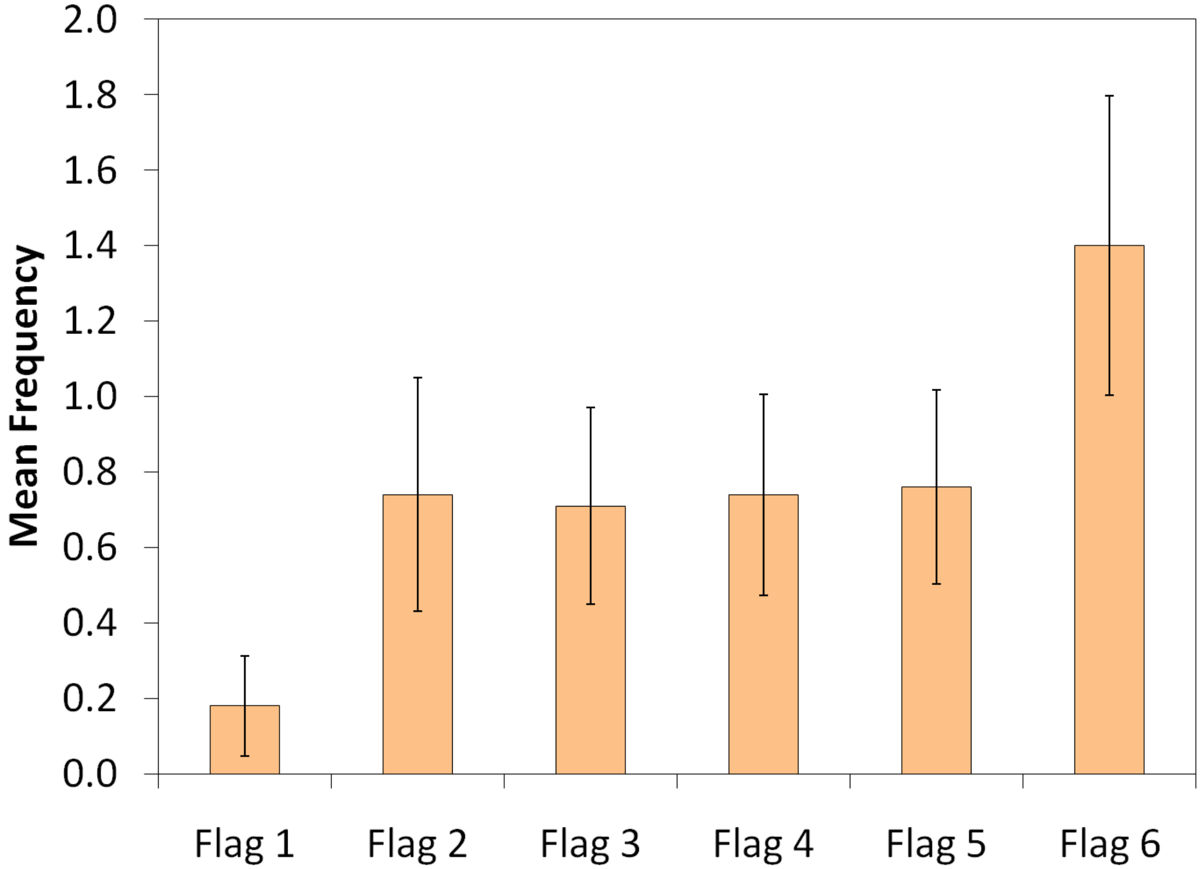


Figure 26. Mean proportion of time touching the map by flag sequence. Flag sequence refers to the flags they visited first, second, etc. and not the color or position of the flags.

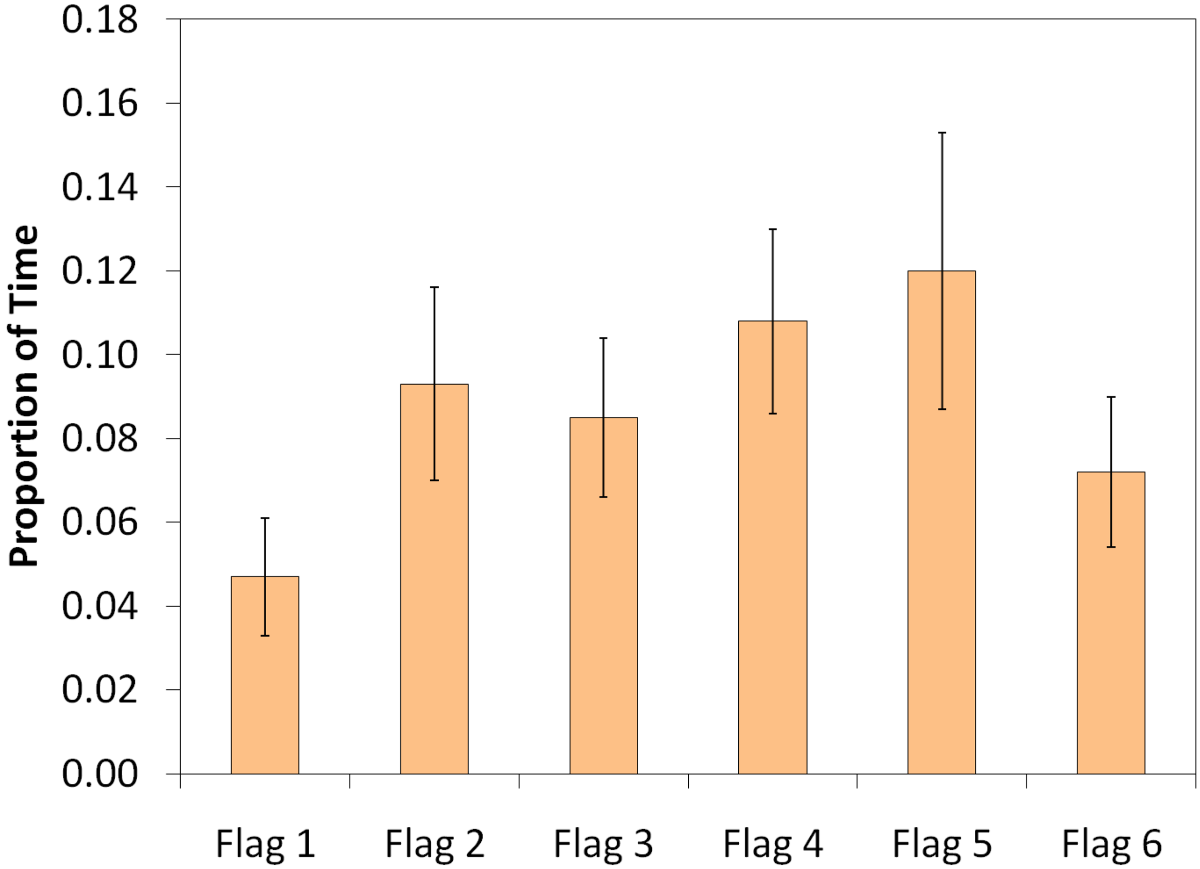


Figure 27.1. Mean map turning and pointing frequency values by latent class. Low refers to what has been labeled the low-aligning class due to the lower rates of turning and aligning the map compared to what has been labeled the high-aligning class, referred to simply as high here.

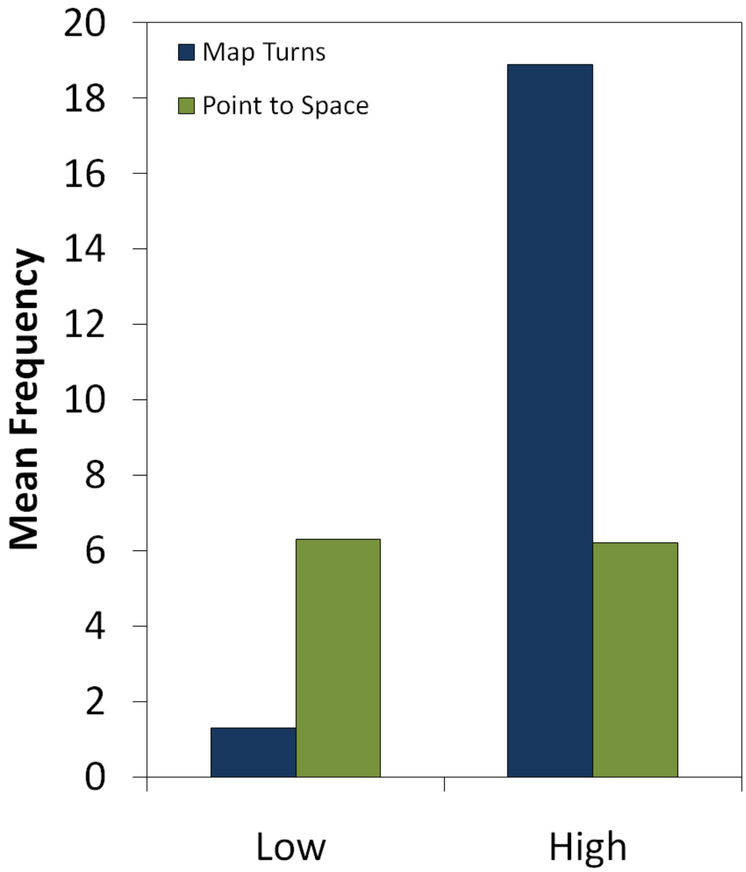


Figure 27.2. Mean looking, aligning, and touching proportion values by latent class. Low refers to what has been labeled the low-aligning class due to the lower rates of turning and aligning the map compared to what has been labeled the high-aligning class, referred to simply as high here.

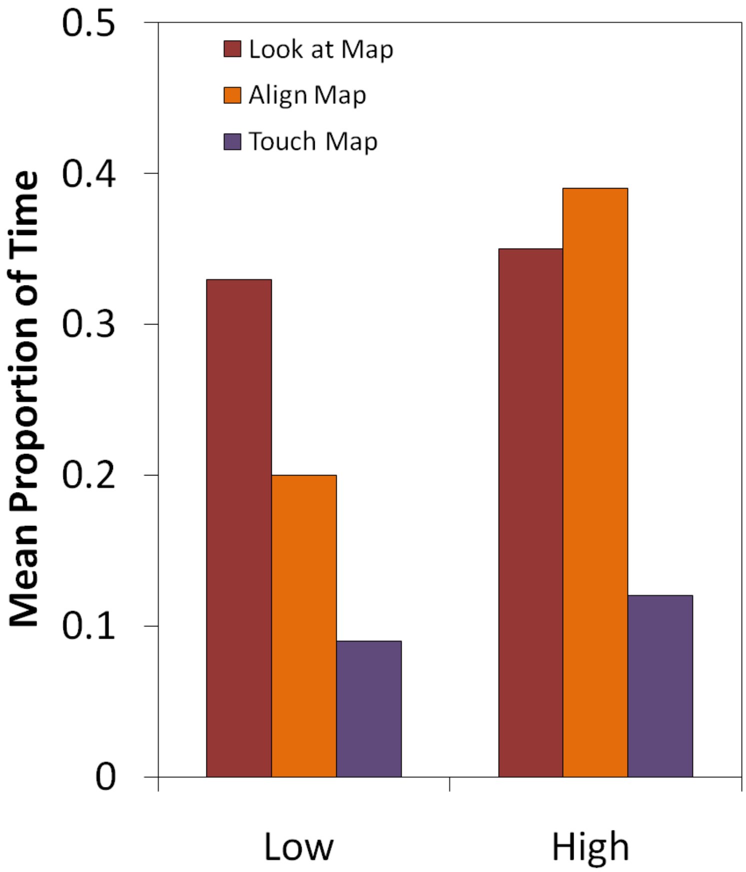
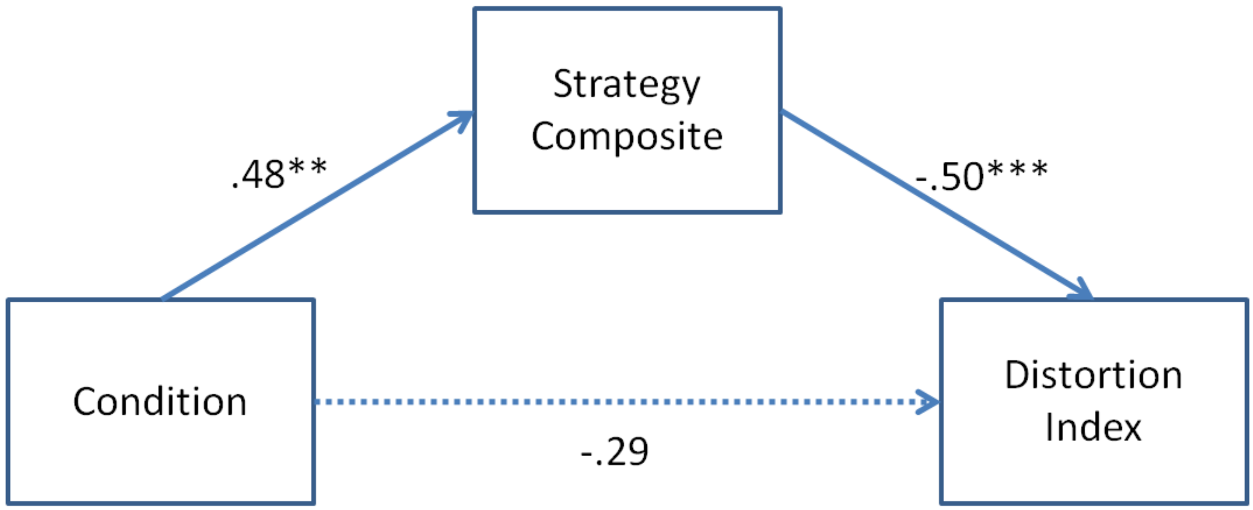


Figure 28. Mediation model illustrating strategy mediates the effect of condition on DI. Note that only the comprehension and production conditions are used in this analysis as the no-map condition did not complete a task that required recording strategies or performance. The production condition was coded as 1 and the comprehension condition as 2 so the positive association with the strategy composite indicates a higher composite score for the comprehension group.



**** *p* < .01**

***** *p* < .001**

Adam E. Christensen
Curriculum Vitae

Education

PhD	The Pennsylvania State University	August 2011	Developmental Psychology
MS	The Pennsylvania State University	December 2007	Developmental Psychology
BS	St. Lawrence University	May 2004	Psychology & Political Science

Experience

Graduate Assistant, Assessment & Evaluation Research, Teaching & Learning with Technology, The Pennsylvania State University, Fall 2010 – Spring 2011

Graduate Research Assistant, Cognitive & Social Development Lab, The Pennsylvania State University, August 2005 – August 2010

Laboratory Manager, Psychological and Brain Sciences, Dartmouth College, August 2004 – July 2005

Teaching Experience

Course Instructor, The Pennsylvania State University, Psychology 200 Elementary Statistics in Psychology (Online), Fall 2009 & Spring 2010

Teaching Assistant, The Pennsylvania State University, Psychology 260 Neurological Bases of Human Behavior, Spring 2008

Teaching Assistant, The Pennsylvania State University, Psychology 485 Leadership in Work, Spring 2006

Teaching Assistant, The Pennsylvania State University, Psychology 413 Cognitive Development, Fall 2006

Publications

Liben, L. S., & **Christensen, A. E.** (2011). Spatial development: Evolving approaches to enduring questions. In: U. Goswami (Ed.) *Blackwell handbook of childhood cognitive development* (pp. 446-472). West Sussex, UK: Wiley-Blackwell.

Liben, L. S., Kastens, K., & **Christensen, A. E.** (2011). Spatial foundations of science education: The illustrative case of instruction on introductory geological concepts. *Cognition and Instruction, 29,* 45-87.

Liben, L. S., **Christensen, A. E.,** & Kastens, K. (2010). Gestures in Geology: The Roles of Spatial Skills, Expertise, and Communicative Context. In: C. Hölscher, T. F. Shipley, M. O. Belardinelli, J. A. Bateman, & N. S. Newcombe (Eds.). *Spatial Cognition VII: Proceeding of the International Conference on Spatial Cognition 2010* (pp. 95-111). Berlin: Springer-Verlag.

Liben, L. S., Myers, L. J., & **Christensen, A. E.** (2010). Identifying locations and directions on field and representational mapping tasks: Predictors of success. *Spatial Cognition and Computation, 10,* 105-134.

Talks

Where am I and where am I going? Spatial predictors of map use performance. Guest Lecture in the Faculty-Student Seminar on Cognitive Development, University of Freiburg, Freiburg Germany. October 16, 2009.

Christensen, A. E. *Map use and survey knowledge acquisition in a large scale, natural environment*. Workshop Presentation at the International Conference on Spatial Cognition, Mt. Hood, Oregon. September 15, 2010.

Selected Conference Presentations

Christensen, A. E., Liben, L. S. (2011). *Not all map use is created equal: Effects of task demands on children's environmental learning.* Poster Presented at the Biennial Meeting for the Society for Research in Child Development.

Christensen, A. E., Liben, L. S. (2010). *The role of map alignment in performance on mapping tasks.* Poster Presented at the International Conference on Spatial Cognition.

Münzer, S., **Christensen, A. E.**, Liben, L. S. (2010). *Finding your way around the environment: Differences and similarities across countries and self-reports.* Poster Presented at the International Conference on Spatial Cognition.