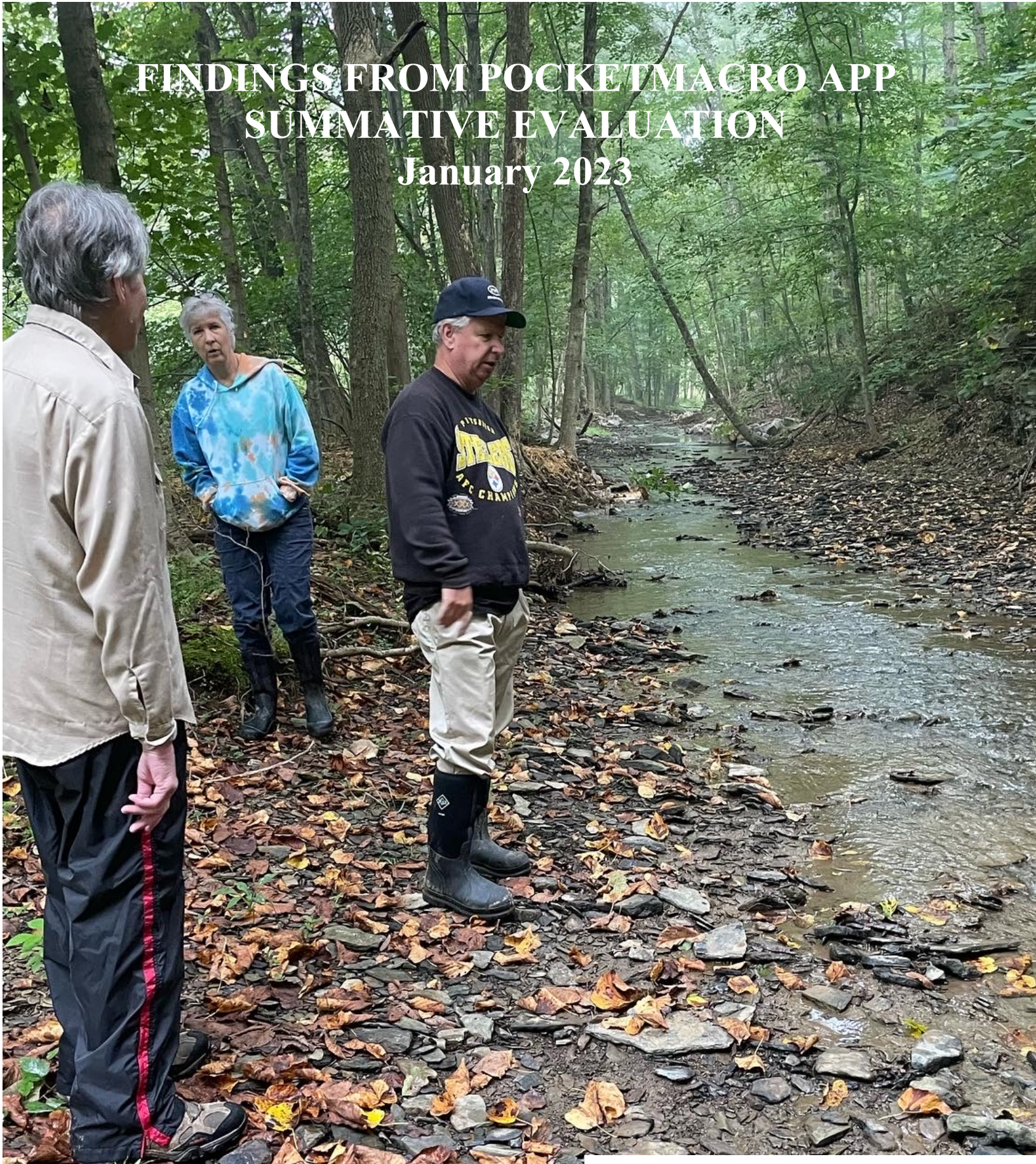
FINDINGS FROM POCKETMACRO APP SUMMATIVE EVALUATION

January 2023



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Dr. Camellia Sanford-Dolly
Director of Professional Development
Rockman et al Cooperative, Inc.

Cover Photo Credit

Selecting locations for stream surveys in Settlers Cabin Park using the PocketMacro app. Photo taken by Ryan H. Ireland.

Project Credits

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About Rockman et al Cooperative, Inc.

Rockman et al Cooperative, Inc. is an employee-owned, innovative research, evaluation, and consulting company that specializes in examining critical issues in formal and informal education. The Rockman team includes evaluators with diverse backgrounds and skillsets who help clients answer critical questions in clear, direct, and honest ways. Rockman et al has served as the lead evaluator for numerous projects funded by the National Science Foundation, as well as several other public and private funding agencies. Learn more at www.rockman.com.

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EXECUTIVE SUMMARY

PocketMacro is a mobile app designed by the Learning Media Design Center at Carnegie Mellon University in collaboration with Stroud Water Research Center, Carnegie Museum of Natural History and Clemson University, and stakeholder input. The PocketMacro app aims to help users better identify benthic macroinvertebrates commonly found in streams and other waterways. Rockman et al Cooperative (REA), an independent educational evaluation group, designed a summative study to explore the effectiveness of the app in supporting users' aquatic macroinvertebrate identification (ID). In Fall 2022, sixty-four participants with varying levels of ID experience were recruited to participate in the study. The purpose of the summative study was to compare the affordances and impacts of digital and print materials on participants' knowledge, accuracy, and confidence related to aquatic macroinvertebrate identification. Participants were randomly assigned to one of three conditions: 1) Those who only practiced aquatic macroinvertebrate identification using the **PocketMacro app**, 2) those who only practiced using a **printed dichotomous key** and **flashcard deck**, and 3) those who practiced using both the above **digital** and **print materials**. Study participants completed a pre-survey before receiving the materials, practiced with the materials they were given for a least 90 minutes, and then completed a resource usage log and post-survey. Ten participants who used the PocketMacro app or both the app and print resources were interviewed about their experiences afterwards. Key findings have been synthesized below.

KEY FINDINGS

THE POCKETMACRO APP

- **The app supported users' developing identification skills.** Most users thought the app:
    - was better than other tools they had previously used to practice ID (98%)
    - was effective at helping them practice ID outside of trainings (90%)

- was useful for identifying an unknown specimen during practice (92%) and in the future (98%)

- **The app supported users' developing observational practices.** Most users thought the app:
  - Made it easier for them to see the relevant features (98%)
  - Helped them distinguish between insect groups (98%)
  - was useful for viewing images of macroinvertebrates more closely during practice (100%) and in the future (98%)
  - was useful for seeing Order level features during practice (98%) and in the future (98%)
  - was useful for seeing Family level features during practice (87%) and in the future (98%)
- **The app increased users' accuracy and confidence in their identifications.**
  - Most users thought the app had increased their accuracy in identifying aquatic macroinvertebrates (98%) and confidence in doing so (98%)
  - App users experienced a significant increase in their accuracy while identifying unknown specimens at the Order and Family levels.
  - App users experienced a significant increase in their confidence while identifying unknown specimens at the Order and Family levels.
  - After practice, app users made significantly more attempts to ID an unknown aquatic macroinvertebrate at the Family level than beforehand
- **The app supported users' ability to support others' learning about aquatic macroinvertebrates.** Most users thought the app:
  - Was useful for helping others learn about macroinvertebrates in the future (95%)
  - Was better than other tools they had previously used in making aquatic macroinvertebrates accessible to others (82%)
  - Was better than other tools they had previously used for engaging students and volunteers with aquatic macroinvertebrates (81%)
  - Would be easy to integrate into their lessons (93%)

- Would help them address educational standards (87%)
- Would enhance their program offerings (71%)

- **App users experienced a significant increase in their knowledge of aquatic macroinvertebrate ID after practicing with the PocketMacro app (from 4.3 to 5.6, on a scale from 1 to 10).**

AFFORDANCES OF DIGITAL AND PRINT TOOLS

- **Practice doing aquatic macroinvertebrate identification, regardless of whether it occurred with the print or the digital tools, had positive impacts on users.**
  - There were no significant differences between those who only used the PocketMacro app, those who only used the printed key and flashcards, or those who used both digital and print resources, regarding participants':
    - Knowledge of aquatic macroinvertebrate ID
    - Perceived confidence in identifying aquatic macroinvertebrates
    - Accuracy in identifying unknown aquatic macroinvertebrates at the Order and Family levels
    - Confidence in identifying unknown aquatic macroinvertebrates at the Order and Family level
    - Attempts to ID an unknown aquatic macroinvertebrate at the Family level
  - Those who used a combination of the print and digital tools experienced significant increases in their confidence in:
    - Collecting aquatic macroinvertebrate samples
    - Determining water quality based on aquatic macroinvertebrate identification
    - Using paper or digital tools to identify aquatic macroinvertebrates
    - Teaching others how to identify aquatic macroinvertebrates
    - Accessing the tools needed to improve their own knowledge of and teaching about aquatic macroinvertebrates

- The PocketMacro app, the printed key, and flashcards were all seen as useful for helping others learn about macroinvertebrates in the future.

- Users liked several features of the PocketMacro app, and thought the app was specifically **useful during the actual identification process to Order or for going deeper into Family level diagnostic features**.
  - Users appreciated the **quality and variety of the app's zoomable images**, allowing them to see specific features closely
  - Users liked having **the Field Guide, ID Key, and Flashcard information all packaged conveniently in one portable resource**
  - **Users disliked that the ID Key only presented one question at a time, making it difficult to compare across Orders**
- Users viewed the Flashcards as **a powerful tool for studying Orders, but not for conducting actual identifications in the field or lab**.
  - Users liked the **combination of photographs and drawings**, as well as the **presentation of information about different feeding groups and key features**
- Users thought the printed key was **useful during the actual identification process to Order, but not for going to Family**.
  - Users liked **having all of the Orders visible for comparative purposes on the poster side of the tool,** as well as being **able to see all of the steps in the ID process at once on the key side**
  - Users thought that **diagnostic features were hard to see on the key**
  - Some users liked the printed key's portability, while others thought it would be difficult to carry into the field
- **The PocketMacro app was viewed as more effective than the other two resources in several areas related to identification and observational practices, and engaging others with aquatic macroinvertebrates.**
  - The PocketMacro app was significantly more likely than flashcards to:
    - Be useful for IDing unknown specimens in the future
    - Be useful for viewing images closely during practice or in the future

        - Be useful for seeing Order level characteristics during practice and in the future
    - The PocketMacro app was significantly more likely than the printed key to:
        - Be better than other tools at making aquatic macroinvertebrates more accessible to others
        - Be better than other tools at engaging students and volunteers with aquatic macroinvertebrates
        - Be useful for seeing Order level characteristics during practice and in the future

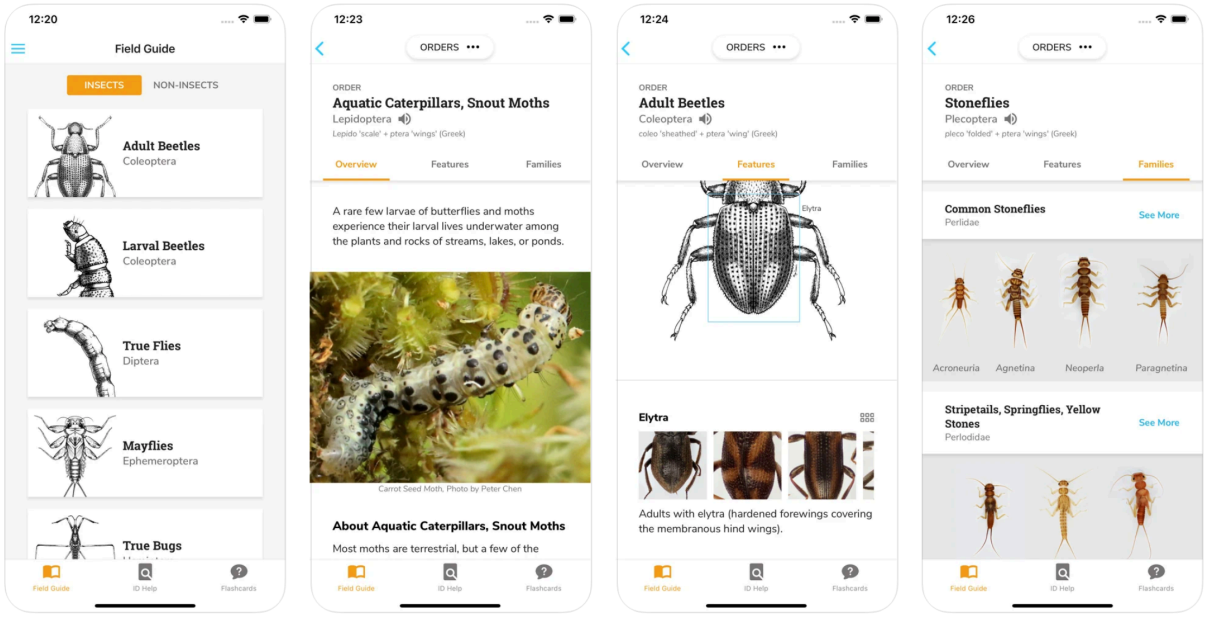
- **The printed key was viewed as less effective than the other two resources in several areas related to learning about aquatic macroinvertebrates, accurate ID, identification and observational practices.**
    - The printed key was significantly less likely than the flashcards or app to:
        - Be viewed as better than other tools for learning about aquatic macroinvertebrates
        - Be useful for quizzing oneself in the future
        - Be perceived as supporting increases in accurate ID
        - Be easier to see relevant features for IDing aquatic macroinvertebrates
        - Be useful for viewing images closely and for viewing Family level features during practice and in the future

In sum, the PocketMacro app, printed key, and flashcards individually, and in combination, effectively supported users in practicing aquatic macroinvertebrate identification. The print and digital tools had slightly different affordances, which impacted participants' understanding, accuracy, confidence, and ability to observe key diagnostic features at the Order and Family levels. The findings above suggest that using a combination of the three tools to practice identification may yield the most positive results. For doing actual identification, especially at the Family level, or for engaging volunteers or students in aquatic macroinvertebrate identification, the PocketMacro app is likely to be the best tool to use based on users' responses.

PROJECT DESCRIPTION

As part of a National Science Foundation-funded effort, The Human-Computer Interaction Institute at Carnegie Mellon University, alongside the Carnegie Museum of Natural History, Stroud Water Research Center, and Clemson University, developed PocketMacro, a mobile app version of The Atlas of Common Freshwater Macroinvertebrates of Eastern North America (www.macroinvertebrates.org). The app features the nine major Orders of aquatic insects and other benthic macroinvertebrates commonly used in volunteer water quality biomonitoring research and environmental education activities (see Figure 1).

FIGURE 1: SCREENSHOTS FROM THE FIELD GUIDE SECTION OF THE POCKETMACRO APP



EVALUATION METHODS

To examine the use and effectiveness of the PocketMacro app, independent evaluators from Rockman et al Cooperative (REA) designed a quasi-experimental study to compare the impacts of digital and print tools on users' knowledge, confidence, and

accuracy related to aquatic macroinvertebrate identification. The study's guiding research questions included:

- What are the affordances of different digital or print tools used to practice aquatic macroinvertebrate identification (i.e., the PocketMacro app, a printed dichotomous key, and printed flashcards)?
- Does practice with the PocketMacro app support users':
  - Self-reported knowledge of and learning about aquatic macroinvertebrates?
  - Identification skills and associated observational practices?
  - Accuracy and confidence in identifying unknown insect specimens at the Order or Family level?
  - Perceived ability to effectively train volunteers or students?
- How do the above impacts compare with users who only used print materials and those who used both print and digital materials to practice identification?

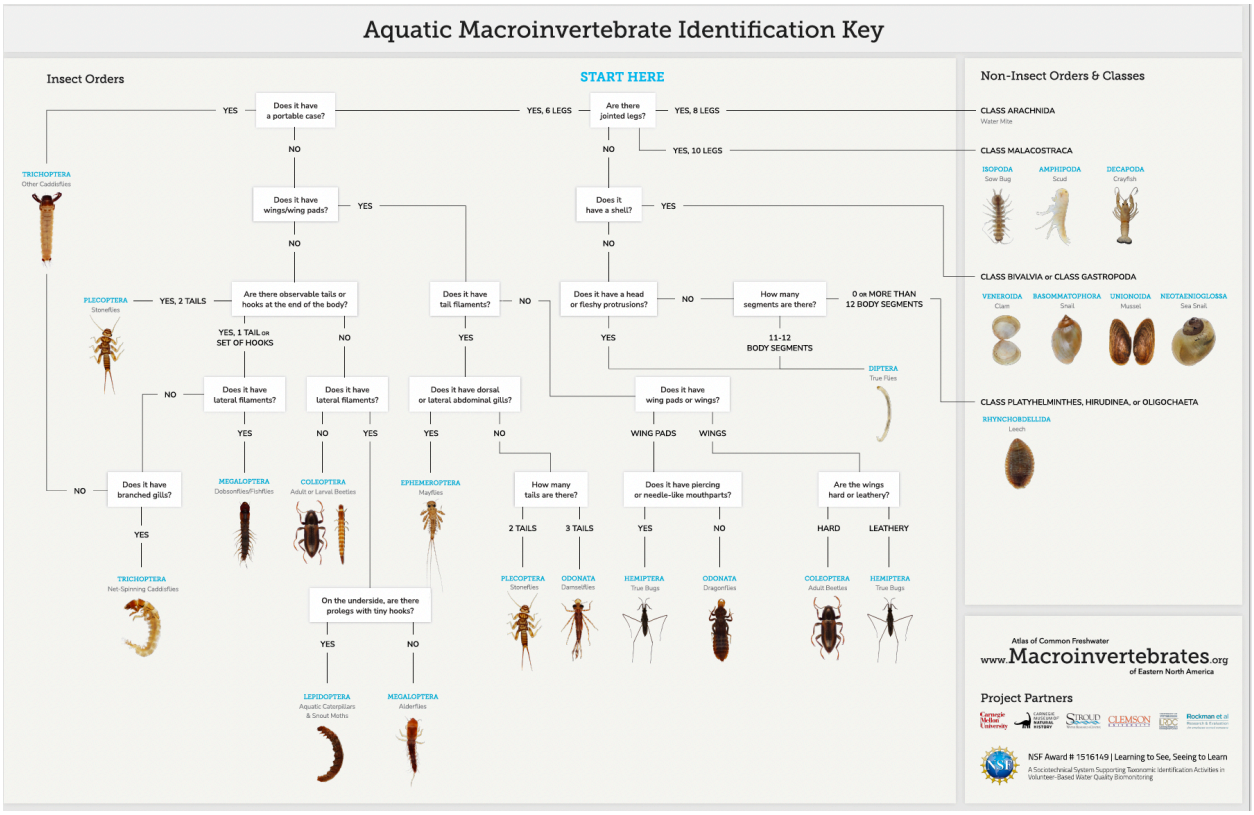
The study design included three conditions: **Digital only** (those who only practiced ID with the PocketMacro app**), Print only** (those who only practiced ID with a printed dichotomous key (see Figure 2) and flashcards (see Figure 3)), and **Digital & Print** (those who practiced ID with the PocketMacro app, printed key and flashcard resources). A balanced mix of individuals who were novice-level, intermediate-level, and expert-level in aquatic macroinvertebrates identification were included in each study condition.

The study took place from mid-August to mid-October 2022. Potential participants were recruited via email from a list of individuals and organizations with connections to volunteer land conservation, watershed, or water quality biomonitoring organizations; universities and colleges with programs with an aquatic macroinvertebrate training component; or those who had participated in a past training associated with project partners. The email invited potential participants to take a pre-survey (*See Appendix A for survey instrumentation*).

Both the pre- and post-surveys included questions asking participants to rate their knowledge of and confidence around aquatic macroinvertebrate identification activities,

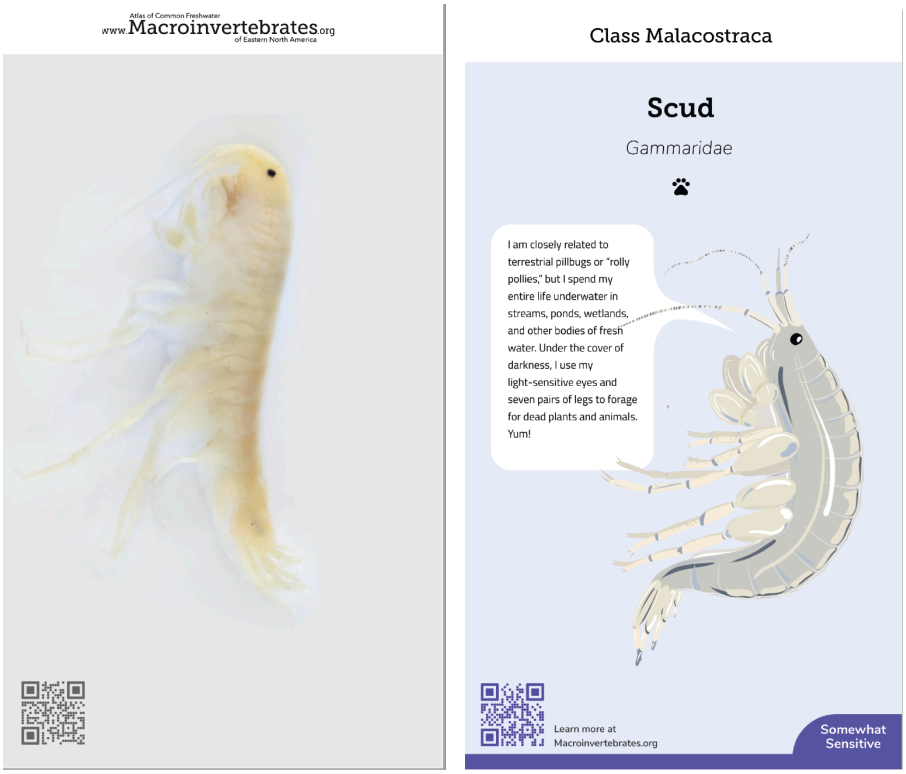
and included an ID accuracy quiz where they were asked to use any resources they had available to identify 21 unknown specimens at the Order level. Participants had the option to attempt Family level identification and were asked to report on their level of confidence in their IDs for both Order and Family level identifications. The pre-survey also contained demographic information about participants, including previous trainings and familiarity with identification. Post-survey questions included what users found valuable about the digital app, printed key, and printed flashcards, as well as suggestions they had for future improvement. The post-survey prompted respondents to reflect on how the digital and print materials supported the development of their own aquatic macroinvertebrate identification and observational skills, as well as their confidence in their ability to teach or train students and volunteers using these resources.

FIGURE 2: SCREENSHOT OF PRINTED DICHOTOMOUS KEY



Photography by: Andrea Kautz, Carnegie Museum of Natural History

FIGURE 3: SCREENSHOT OF A PRINTED FLASHCARD OF A SCUD WITH QR-CODE LINKING TO THE ASSOCATED MACROINVERTEBRATES.ORG PAGE



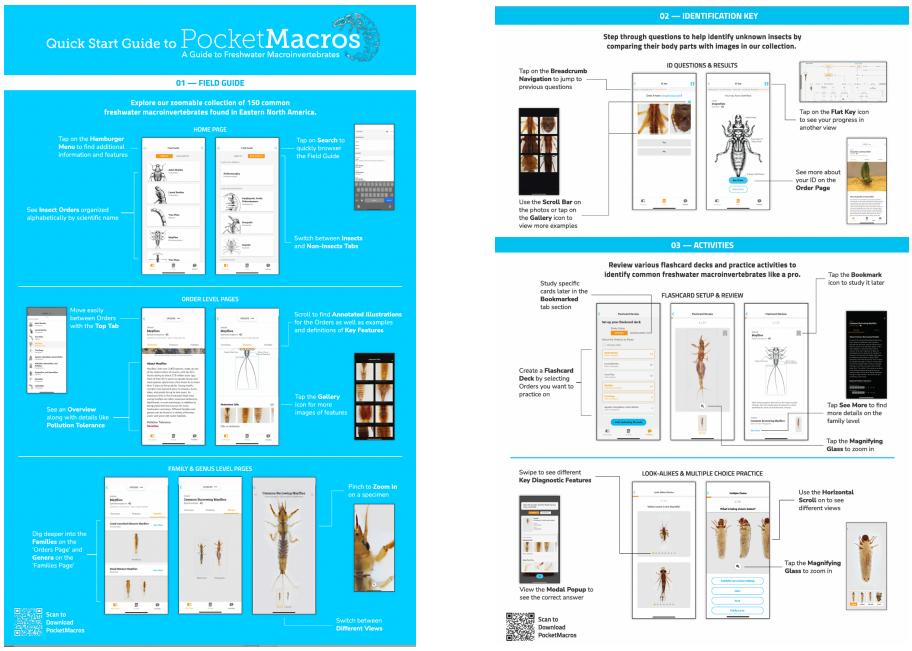
Photography by: Andrea Kautz, Carnegie Museum of Natural History
Aquatic Macroinvertebrate Card Illustrations by: Ricky Chen and Karis Wang

Participants were selected for the study based on their scores on the pre-survey's ID accuracy quiz, with the goal of including a similar number of participants who were novice-level (identified 0-7 specimens correctly at the Order level on the pre-survey), intermediate-level (identified 8-15 specimens correctly), and expert-level (identified 16-21 specimens correctly).

Those selected for the study (see "Overall Survey Sample" section below) were randomly placed into one of the three study conditions: Digital only (they only received the PocketMacro app, a QR code for accessing it, and an app user guide via email (see Figure 4)), Print only (they only received a laminated dichotomous key and printed flashcards via mail), and Digital & Print (they received all three resources). Participants were asked to watch an introductory video that defined what benthic freshwater

macroinvertebrates are, some challenges one might encounter when identifying specimens, and some tips to use during the identification process (see Figure 5), spend at least ninety minutes total with the materials provided, and to log the dates and times they utilized each resource in an online Usage Log (*see Appendix C for Usage Log prompts*). On the log, they were also asked to name and describe how they used the resource and to reflect on what they liked or found challenging about each tool.

FIGURE 4: SCREENSHOTS OF THE POCKETMACRO APP USER GUIDE

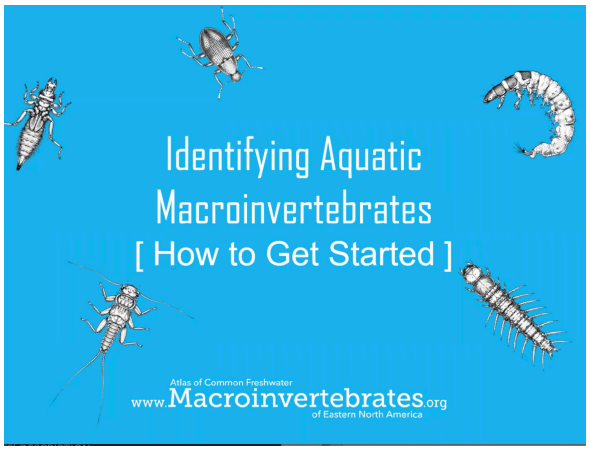


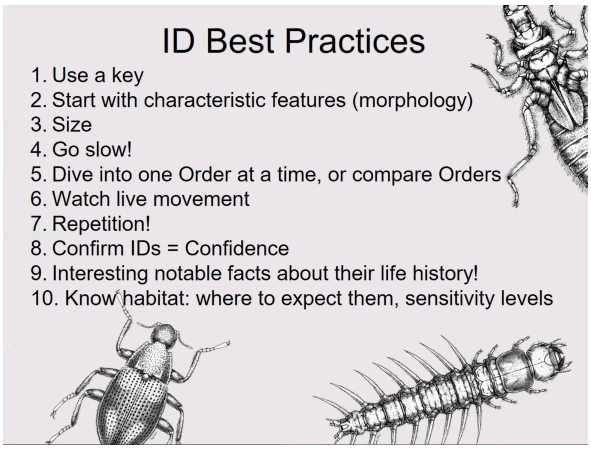
After they completed the log, participants were sent the online post-survey. Once their post-survey was submitted, participants were mailed a $30 gift card and provided with a voucher ($20 value) to take the Society for Freshwater Science Certification Program Exam. In addition, those who were in the Digital Only condition were mailed the print materials and those in the Print Only condition received links to the PocketMacro app.

A subset of ten individuals who were either in the Digital Only or Digital & Print conditions were invited to participate in a 30-minute interview via the Zoom videoconference platform. Interview questions included probes about users' prior experiences with and opinions of other ID tools and resources, the utility of the

PocketMacro app, printed key, or flashcards for doing ID, specific likes and dislikes, and their preferences for print or digital study materials (*See Appendix B for the interview protocol*). They received an additional $20 online gift card for their participation.

FIGURE 5: SCREENSHOTS FROM THE INTRODUCTORY VIDEO





PARTICIPANTS' DESCRIPTION

OVERALL STUDY SAMPLE

Sixty-four individuals participated in the larger study[1]. There was a fairly even balance between those who were novice-level (identified 0-7 specimens correctly at the Order level on the pre-survey), intermediate-level (identified 8-15 specimens correctly), and expert-level (identified 16-21 specimens correctly; see Table 1). There was also a fairly even distribution of participants across the three study conditions of those who only practiced with digital tools, those who only practiced with print materials, and those who used both the print and digital resources provided.

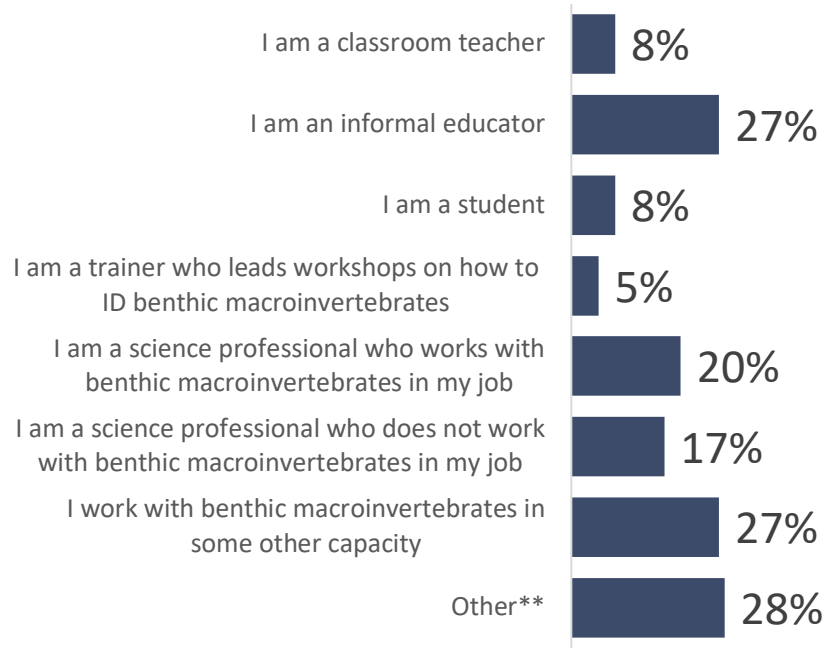
[1] *183 individuals took the pre-screening survey, with 24 respondents being ineligible for the study because they scored 21 out of 21 on Order level identifications on the ID accuracy quiz and an additional 13 not providing mailing addresses. Of the remaining 146 potential participants, 90 individuals, representing a balance of the three knowledge conditions, were invited to participate in the study via email. 73 of these individuals confirmed their initial willingness to participate in the study, and 65 completed the study. One individual was removed from the dataset for providing SPAM responses, resulting in a total of 64 study participants.*

TABLE 1: PARTICIPANTS BY STUDY CONDITION

	Digital Only	Print Only	Both Digital & Print	TOTAL
Novice-Level	8	6	8	22
Intermediate-Level	6	8	8	22
Expert-Level	6	7	7	20
TOTAL	20	21	23	64

The majority of survey respondents self-identified as female (67%) and White (95%). The average age of study participants was 42 years of age. Participants tended to be informal educators (27%), those who work with benthic macroinvertebrates in some other capacity (27%), or selected "Other" (28%; see Figure 6).

FIGURE 6: STUDY PARTICIPANTS' OCCUPATIONS (N=64)*



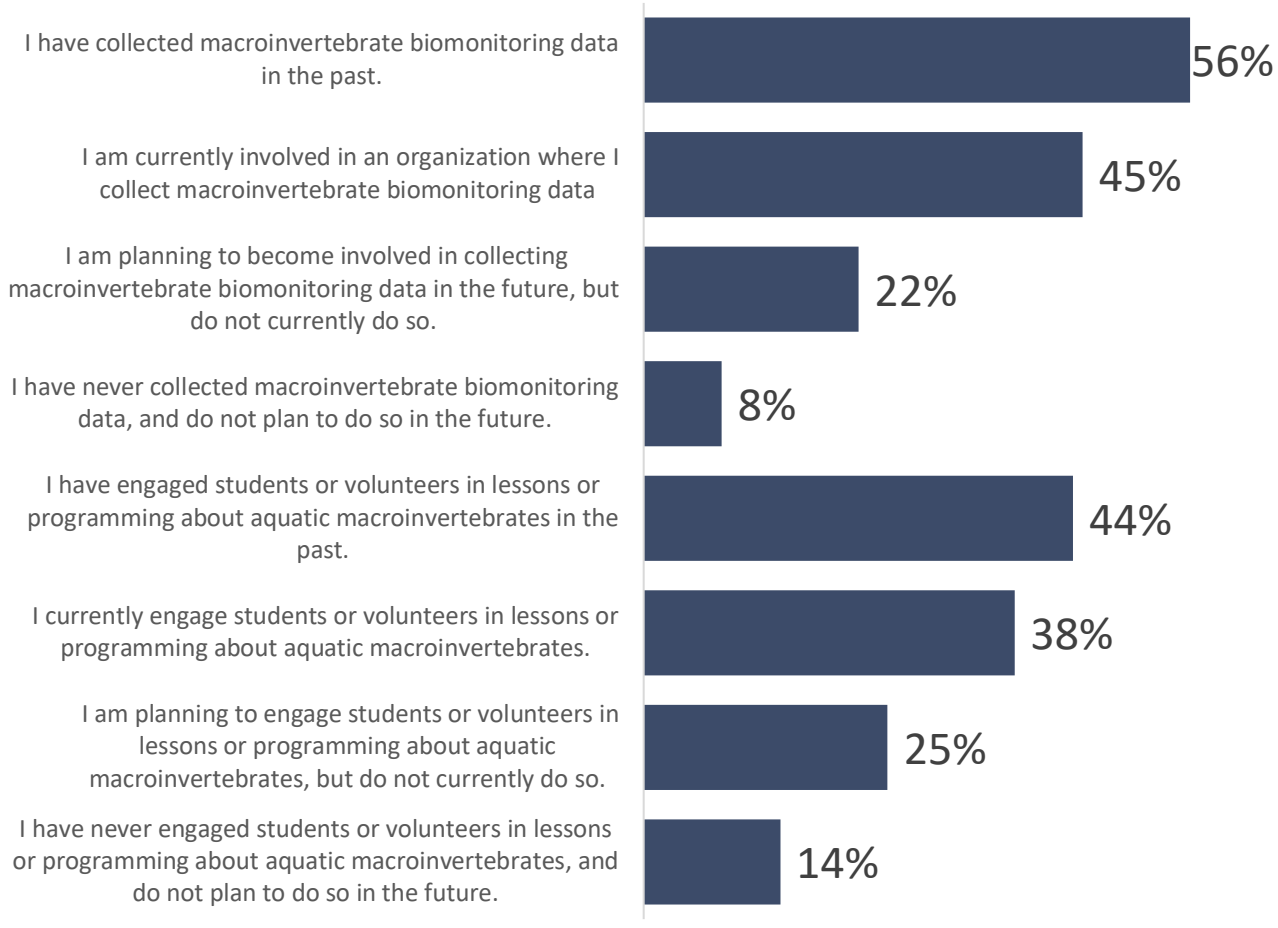
** Respondents could select more than one option.*

*** "Other" includes retirees, employees at watershed, water quality, or land conservation organizations, Master Naturalists, volunteer water quality monitors, concerned citizens, and interns.*

The majority of participants (72%) had participated in some kind of training in aquatic macroinvertebrate identification before. These trainings tended to be with local

watershed or naturalist groups, state departments, or via college courses. Some participants (38%) had visited the Macroinvertebrates.org website prior to the study[2]. Only a few (17%) had participated in a training where Macroinvertebrates.org resources had been introduced or demoed. Over half of the participants had collected macroinvertebrates biomonitoring data in the past, but less than half were currently doing so and less than a quarter planned to do so in the future (see Figure 7). Participants were less likely to have engaged students or volunteers in lessons or programming in the past, present, or future. Very few attendees had never done any of these activities nor planned to do so in the future.

FIGURE 7: STUDY PARTICIPANTS' PRIOR EXPERIENCES (N=64)*



** Respondents could select more than one option.*

[2] *Prior exposure to macroinvertebrates.org did not exclude participants from the study.*

Interviewees

Ten study completers were invited to participate in follow-up interviews. Of these, seven used both the digital and print materials, and three only used the PocketMacro app. Two were male, and the remainder were female. Five interviewees were novices at doing aquatic macroinvertebrate identification, three were intermediate level, and two were experts.

FINDINGS

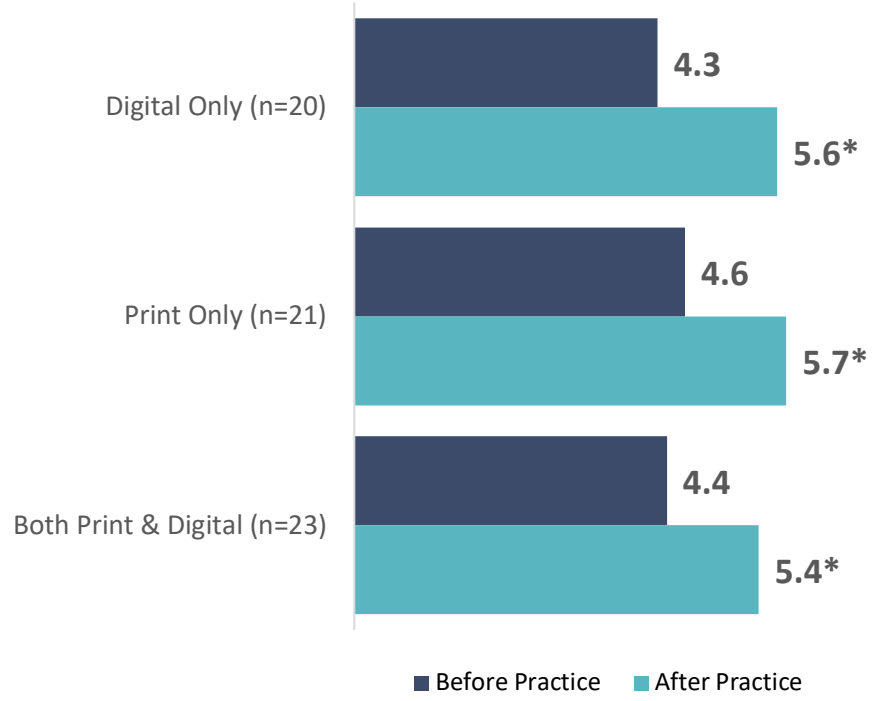
IMPACTS OF THE DIGITAL & PRINT RESOURCES

The App Supports Increased Knowledge Of Aquatic Macroinvertebrates

PocketMacro app users self-reported a **significant increase in their knowledge about aquatic macroinvertebrates identification after practicing ID with the app** (see Figure 8). When looking at prior experience identifying macroinvertebrates, those at the intermediate-level (i.e., they correctly identified between 10 to 15 specimens at the Order level before they received the digital or print tools) specifically reported a significant increase in their ID after practicing solely with the app. However, even expert-level users benefitted, with one stating, *"I'm definitely kind of like a 'quiz myself' type of learner, so that really helped it stick. I saw an increase in my knowledge and ID at the Order level. My goal is to keep using the app and kind of get some families down."*

There were no significant differences between those who just used the app, those who just used the flashcards and dichotomous key, and those who practices with both resources in terms of perceived knowledge gains. This was true when exploring any potential differences between the three conditions within the three experience levels (i.e., looking just at novice-level users, then just at intermediate-level, or just expert-level). This result suggests that practice, regardless of whether it occurs with print or digital tools, positively impacts knowledge of aquatic macroinvertebrate ID.

FIGURE 8: CHANGES IN RESPONDENTS' KNOWLEDGE AFTER USING THE DIGITAL OR PRINT RESOURCES**



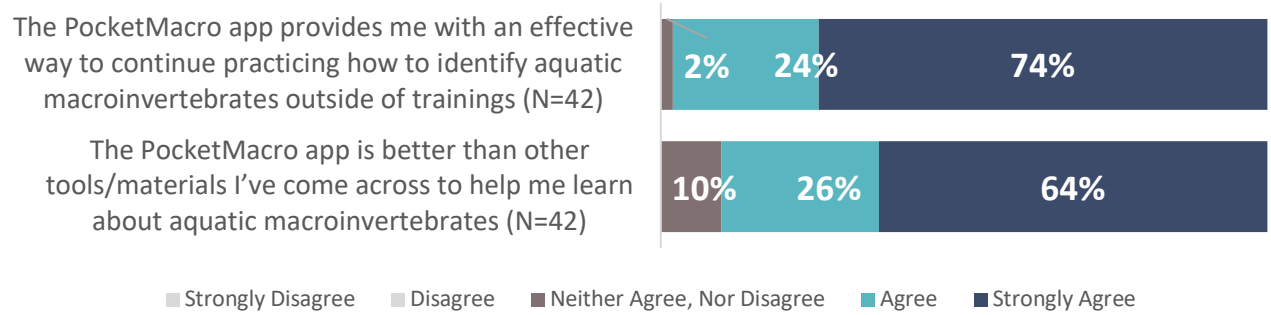
** Indicates a statistically significant difference at the p<.05 level.*
*** On a scale from 1 to 10, with 1 being, "I have no familiarity at all with aquatic macroinvertebrates," and 10 being, "I am an aquatic macroinvertebrate expert."*

THE APP SUPPORTS PRACTICING IDENTIFICATION SKILLS

The PocketMacro app was effective at helping users continue to practice how to identify aquatic macroinvertebrates outside of trainings (see Figure 9) – 90% of survey respondents agreed or strongly agreed that the app did so. One expert-level participant noted, *"So I feel like [the PocketMacro app] really kind of helped me solidify my Order identification greatly...You can open up and look more into the specific Families and Genera within those Families...Step-by-step...You kind learn your way down the taxonomy."* Another expert-level app user shared, *"The functionality in accessing Families within Orders and the accompanying pictures are extremely useful in studying. The features tab with labeling is also a helpful general-use tool to identify Order quickly. It was also helpful that I could go over identification from anywhere while using the app."* A novice-level participant used the app to try *"to figure out my 'problem*

areas' of identification, particularly 'seeing' wing pads and gills." A few study participants shared examples of using the app to ID an unknown specimen. For example, one novice-level participant *"used this tool to identify a bug I found outside my apartment in the Huron River. I identified it as a True Fly."*

FIGURE 9: THE APP WAS AN EFFECTIVE TOOL FOR PRACTICING IDENTIFICATION & LEARNING ABOUT AQUATIC MACROINVERTEBRATES



App users also thought that the PocketMacro app was better than other tools they had previously used to practice ID – 98% of survey respondents agreed or strongly agreed with this statement. Several participants noted **that the ability to zoom, the variety of examples available, and ease of use all made the app superior to print resources they had used in the past***:*

> *"Everything we had been using was print, and the fact that you can zoom in on photographs and have diagramed illustrations and run through flashcards and whatnot - I think it just kind of opens up possibilities in that sense. So it takes away the limitations that a hard copy or print copy resource might have."*
> – Expert-level

> *"[The PocketMacro app] was superior because of the pictures, the ability to zoom in, the amount of information, the whole algorithm to find things on the ID key that it had in there. I mean, it was just superior to anything else I've ever used. I mean, I had flashcards with me - not the ones that we were supplying with, but my old ones. You had a handful of them and it was like, 'Okay, well it either looks like this or it looks like this, and there wasn't much variation."* – Intermediate-level

"Field guides are great because they do add that extra information, but they're really hard to use on-the-fly. You have to know exactly what page you need to go to. It's really not the kind of thing you can just like casually flip through, this 500-page field guide about macroinvertebrates while you're teaching middle school students." – Novice-level

In comparing the digital app to the two print-based tools, **survey respondents were significantly more likely to state that the app and the flashcards were better than other tools they had encountered compared to the traditional dichotomous key** (see Table 2).

TABLE 2: COMPARING PRINT & DIGITAL TOOLS FOR PRACTICING IDENTIFICATION & LEARNING ABOUT AQUATIC MACROINVERTEBRATES

	PocketMacro App (n=42)	Printed Key (n=44)	Printed Flashcards (n=45)
Provides me with an effective way to continue practicing how to identify aquatic macroinvertebrates outside of trainings	4.71	4.66	4.67
Is better than other tools/materials I've come across to help me learn about aquatic macroinvertebrates	4.55+	4.07**+	4.42**

** On a scale from 1 to 5, with 1 being, "Strongly Disagree," and 5 being, "Strongly Agree."*
*** Indicates a significant difference at the p<.05 level.*
+ Indicates a significant difference at the p<.05 level.

Most users thought that the PocketMacro app was useful for identifying unknown specimens when they were practicing ID (92%), and even more thought it would be useful in the future for doing so (98%; See Figure 10). In comparing the digital app to the two print-based tools, **survey respondents were significantly more likely to state that they thought that the app would be better to use in the future than the flashcards for identifying unknown specimens** (see Table 3).

Similarly, most respondents (93%) thought that the app was useful for quizzing oneself (see Figure 11). In comparing the digital app to the two print-based tools, **survey respondents were significantly more likely to state that they thought that the app and the flashcards would both be better to use in the future than the dichotomous key for practicing ID or quizzing oneself** (see Table 4):

> *"I think that the [PocketMacro app and printed flashcards] are a little more user friendly. I don't know. Maybe it was just the way that I think and what I was interested in, but it seemed as though they kept my interest and I found them more effective than the [printed] key."* – Intermediate-level

> *"[With the printed key], you have to like follow like each one and sometimes it's like, 'Oh, I followed one path, but then I got the wrong one. So I guess I have to backtrack.' So I guess it was longer in identifying compared to the app or the flashcards."* – Novice-level

FIGURE 10: USEFULNESS OF THE POCKETMACRO APP TO IDENTIFY AN UNKNOWN SPECIMEN

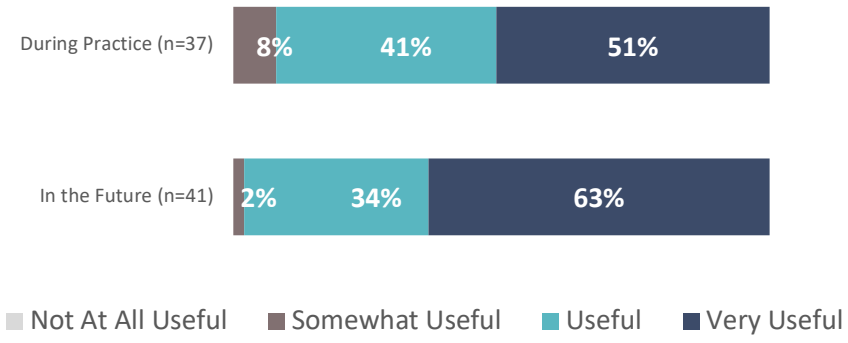


TABLE 3: COMPARING PRINT & DIGITAL TOOLS USEFULNESS IN IDENTIFYING UNKNOWN SPECIMENS

	PocketMacro App (n=37, 41)	Printed Key (n=40,45)	Printed Flashcards (n=42,44)
During Practice	3.43	3.45	3.36
In the Future	3.61**	3.38	3.16**

** On a scale from 1 to 4, with 1 being, "Not at all Useful," and 4 being, "Very Useful."*
*** Indicates a significant difference at the p<.05 level.*

FIGURE 11: USEFULNESS OF THE POCKETMACRO APP TO PRACTICE ID OR QUIZ ONESELF (N=42)

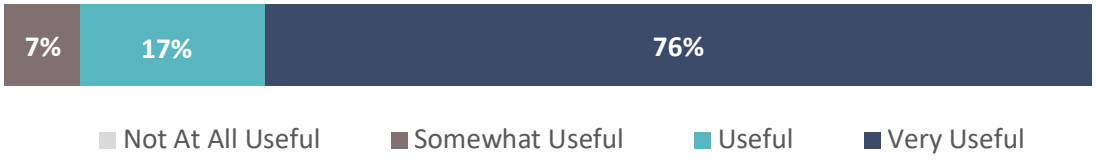


TABLE 4: COMPARING PRINT & DIGITAL TOOLS USEFULNESS IN PRACTICING ID OR QUIZZING ONESELF

	PocketMacro App (n=42)	Printed Key (n=45)	Printed Flashcards (n=45)
In the Future	3.69**	3.31**+	3.82+

** On a scale from 1 to 4, with 1 being, "Not at all Useful," and 4 being, "Very Useful."*
*** Indicates a significant difference at the p<.05 level.*
+ Indicates a significant difference at the p<.05 level.

Those who thought that the app was the best tool for practicing identification liked that the information was all in one place and easily accessible:

> *"The app is superior for sure. It's there. It's in your hand. You got the algorithm. You got the key. If you know what you're looking at, you can just go right to it and pull up the different Families if you want to get real specific. So yeah, the app is just pretty amazing."* – Intermediate-level

> *"I like that I can have a tool with me wherever I am to ID macroinvertebrates. I especially like that it's organized in a way to study, as well as has an ID quiz feature to figure out what you're looking at in real life if you find a macro."*
> – Novice-level

However, a few experienced information overload with the app. One intermediate-level user noted, *"There is a lot of information, and it was easy to get lost if I was just curious about a feature of an Order, then features of a specific Family."* Another intermediate-level user described her preference for a physical key, but acknowledged its limitations: *"I love a key! [It's] great to narrow IDs down to Order. Using the key over and over helps hammer the diagnostic characteristics into my brain. Once you figure out the Order, you're on your own. So if you're looking for a Family or species, you have to use another taxonomic tool."*

Printed flashcards were viewed as a powerful tool for studying, but were seen as less effective during actual specimen identification:

> *"I like being able to manipulate the organization of the tools, like grouping them together by taxa, mixing them up to test myself, or put all the ones I get mixed up together to focus on those."* – Intermediate-level
>
> *"The flashcards were really useful for studying. I don't think the flashcards would be as useful for like identifying out in nature."* – Novice-level
>
> *"I don't know if I would use the flashcards as much when making an actual ID. I think these would be more for me to do practice offline...I think if you're out in the field trying to juggle these or if you're sitting like at a microscope, there's just a lot of things you have to hunt through, and that could get to be messy and complicated."* – Novice-level
>
> *"I didn't really try to use [the flashcards] for ID, but I could see how it would be hard because you're looking at one certain species and one certain picture and there's so many variations among Families in an Order, so it could be difficult plus sorting through all these flashcards trying to find the one that you're looking for, it can be daunting."* – Expert-level

A few study participants who used both tools indicated that they appreciated having both digital and print tools during the identification process:

> *"I think I prefer a mix. I think when you're actually in a boots-in-the-water type situation, it's always nice to have a laminated sheet...But I think it's crucial to have something along these lines where you can, once you've collected specimens - you're kind of back on the banks looking through stuff - then you can pull out your electronic device and kind of get a little more in-depth."*
> – Expert-level

> *"I can see all the bugs at the same time. If I didn't get the right answer on the app, I found the bug on the [printed] key and worked my way back to figure out what I did wrong."* – Novice-level

> *"I could use [the app] in combination with the ID key and the flashcards, so it could help me go further than either of those. I mean, just being able to drill down into the features, the being able to compare and contrast, and being able to look in detail beyond the Order level was helpful."* – Intermediate-level

The App Supports Observational Practices

Interviewees were asked to share general challenges to doing aquatic macroinvertebrate identification. These included the size of the organisms, needing more comparative examples, and lacking knowledge about distinguishing features. One novice-level app user summarized:

> *"They're often very small, and sometimes, you know, you don't have the ability to see them as closely as you would like. The other thing that I think is challenging is, just in general, people don't know what to look for. So, you know, just for the casual person who's trying to look at an insect or some other creature, they may not know the names of the different parts, or know what to look for precisely, and that kind of makes them intimidated to try."* – Novice-level

In particular, **app users appreciated that the PocketMacro app made it easier for them to see the relevant features of an organism, and helped them differentiate between insect groups** - 98% of survey respondents agreed or strongly agreed that the app did so (see Figure 12):

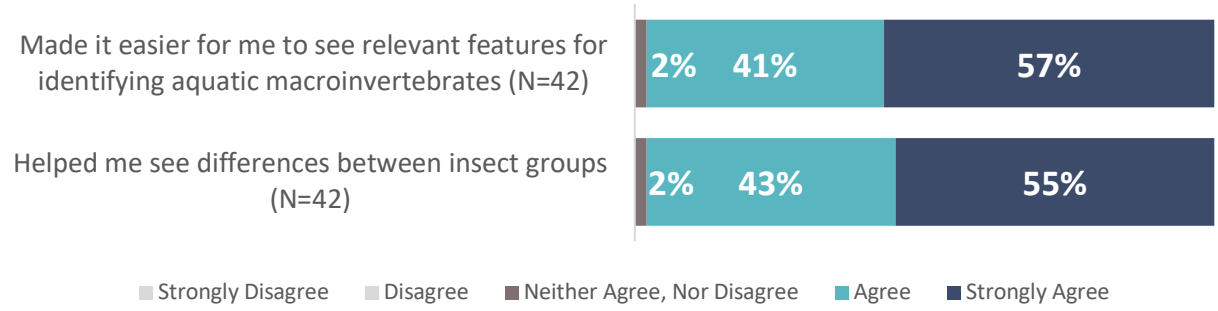
> *"[I liked] the ability to zoom in better to see insect body parts."* – Expert-level

> *"The nice thing about the app is that it really showed those structures that are harder to see."* – Novice-level

> *"Zooming in and seeing features (mimicking a microscope) and having multiple images to explore and compare."* – Expert-level

> *"Just having [the app] accessible if I'm out there working in the field, being able to pull it up and use the key or compare pictures."* – Expert-level

FIGURE 12: THE POCKETMACRO APP AS A TOOL TO SUPPORT OBSERVATIONAL PRACTICE



In comparing the digital app to the two print-based tools, **survey respondents were significantly more likely to state that the app and the flashcards made it easier for them to see relevant features needed for identification than the traditional dichotomous key** (see Table 5). Participants acknowledged that the images on printed keys were often small, making distinguishing features hard to recognize:

"The clear photos and black and white drawings. It can be difficult to really see the features just from one single image on an ID key, so the options on this app were great." – Intermediate-level

"Practicing with the key can be tricky. I try to look at pictures of different macros and use the key to identify them. Pictures can be tough because it can be hard to spot little details on bodies and figure out which species I am looking at. Not every feature is easy to see." – Expert-level

TABLE 5: COMPARING PRINT & DIGITAL TOOLS FOR SUPPORTING OBSERVATIONAL PRACTICES

	PocketMacro App (n=42)	Printed Key (n=44)	Printed Flashcards (n=45)
Made it easier for me to see relevant features for identifying aquatic macroinvertebrates	4.55**	4.20**+	4.67+
Helped me see differences between insect groups	4.52	4.57	4.42

** On a scale from 1 to 5, with 1 being, "Strongly Disagree," and 5 being, "Strongly Agree."*
*** Indicates a significant difference at the p<.05 level.*
+ Indicates a significant difference at the p<.05 level.

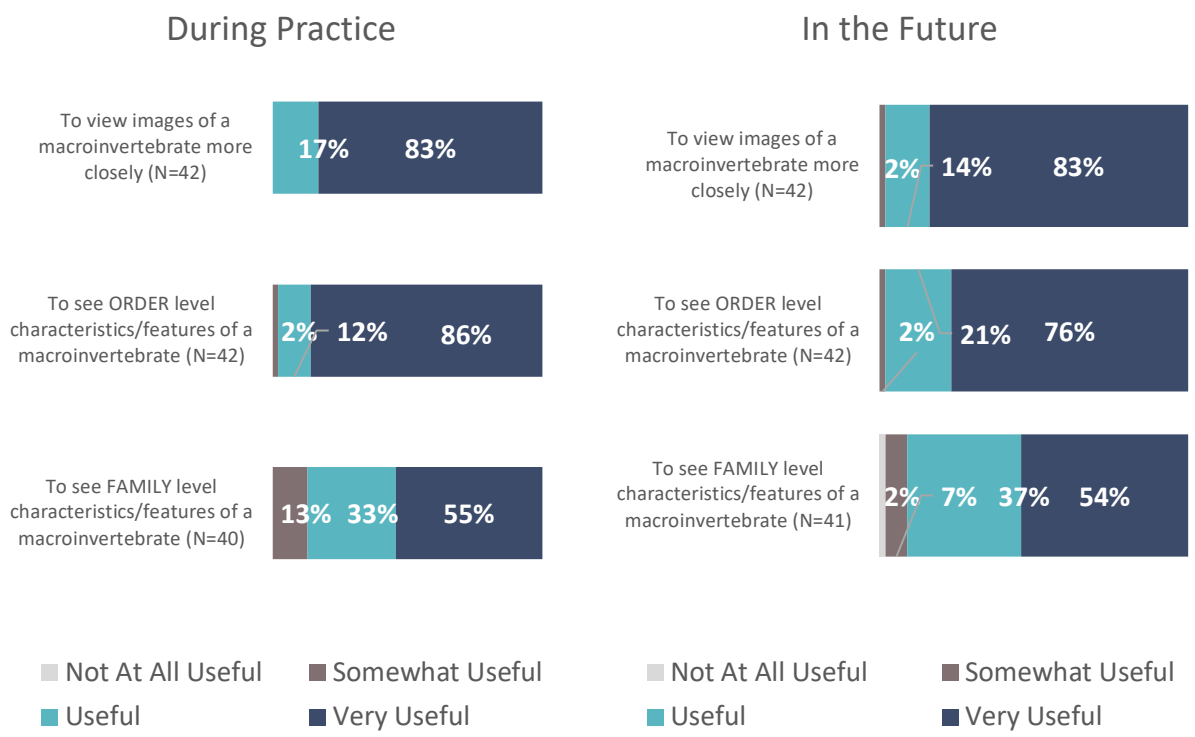
Almost all survey respondents felt that **the app was useful for viewing images closely during practice (100%) and in the future (98%)**. seeing Order and Family level characteristics while practicing identification for the study and in the future (see Figure 13):

"The app can kind of bridge that [gap]. The key [we use at our organization] is just small - illustrations, not photographs. Obviously, you can't zoom in on it like you can on the app. The photographs in the app are incredibly detailed, so it kind of really opens up that world." – Expert-level

"I liked the explanations of each macroinvertebrate and seeing the pictures of their bodies up close. For example, I finally understand what a wing pad is, whereas before that always confused me." – Novice-level

"I was thinking of things that had hooks and I was like, 'Well what do they mean by hooks? Like are they big? Are they small?' So I could look at the picture and say, 'Oh, it varies in shape and size.'...Once you get to a certain space, you can see the Order and then you can go through Families and there are a lot of pictures in there that make it very easy for you to pick out those Families, which is something I would never have been able to do before, especially with the paper guide." – Novice-level

FIGURE 13: USEFULNESS OF THE POCKETMACRO APP DURING PRACTICE & IN THE FUTURE FOR SUPPORTING OBSERVATIONS



In comparing the digital app to the two print-based tools, **survey respondents were significantly more likely to state that the app and the flashcards were useful for viewing images of macroinvertebrates closely, and for viewing Family level features both during practice and in the future than the printed key** (see Table 6).

Respondents also were significantly more likely to state that the app was more useful for viewing images of macroinvertebrates closely during practice and in the future than the flashcards. In addition, respondents thought that **the app was significantly more useful than the key or the flashcards for seeing Order level characteristics both during practice and in the future**.

TABLE 6: COMPARING PRINT & DIGITAL TOOLS FOR SUPPORTING OBSERVATIONAL PRACTICES

	PocketMacro App (n=40-42)	Printed Key (n=41-45)	Printed Flashcards (n=43-45)
To view images of a macroinvertebrate closely during practice	3.83**+	2.75**Ω	3.48+Ω
To view images of a macroinvertebrate closely in the future	3.81**+	2.62**Ω	3.31+Ω
To see ORDER level characteristics/features of a macroinvertebrate during practice	3.83**+	3.36**	3.52+
To see ORDER level characteristics/features of a macroinvertebrate in the future	3.74**+	3.27**	3.40+
To see FAMILY level characteristics/features of a macroinvertebrate during practice	3.42**	2.49**+	3.33+
To see FAMILY level characteristics/features of a macroinvertebrate in the future	3.41**	2.35**+	3.16+

** On a scale from 1 to 4, with 1 being, "Not at all Useful," and 4 being, "Very Useful."*
** *Indicates a significant difference at the p<.05 level.*
\+ *Indicates a significant difference at the p<.05 level.*
Ω *Indicates a significant difference at the p<.05 level.*

In terms of the app, study participants again cited its zoom functionality as something that set the tool apart from the printed key or flashcards:

> *"I love that you could zoom in on the pictures to get like a better idea compared to like the cards and the key."* – Novice-level

> *"[The app was] easy to navigate and I could zoom in on pictures of insects to better observe legs, mouthparts, gills, tail, etc."* – Expert-level

Participants' opinions were a bit more mixed regarding the printed flashcards. Some preferred the tool over the printed key, while others sought more detailed images and diagnostic characteristics like the app had:

> *"I think they make it a little more interesting to look at. It makes you want to learn a little bit more. It's a lot easier than just, you know, looking through a key. I think they really helped, [and] did a good job to kind of outline the major differentiating factors of the macro."* – Intermediate-level

> *"You can't zoom in! If you're looking for a hook or wing pads, it can be hard to see on a printed card.*" – Intermediate-level

> *"I wish there were more diagnostic features labeled on each flashcard. What should I be looking at? What defines the Family? Should I be assuming that the things mentioned about each Family on the card are specific to that Family?"* – Expert-level

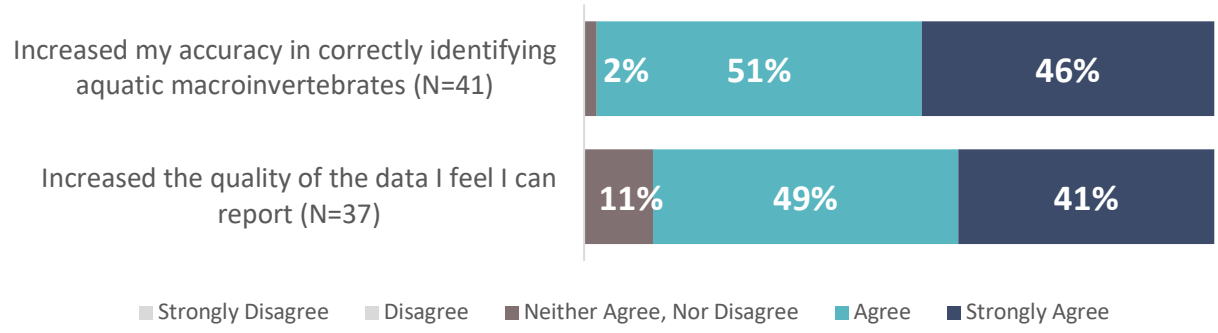
The App Increases Accuracy

Almost all app users (98%) agreed that using that app had increased their accuracy in identifying aquatic macroinvertebrates (see Figure 14). Many app users (89%) also agreed that the app had increased the quality of the data they felt they could report. On an assessment where they were asked to identify 21 different specimens before and after practicing with only the app as a tool, **app users (n=20) were able to correctly identify significantly more aquatic macroinvertebrates at the Order level[3] (~12 before versus ~17 specimens after), and at the Family level[4] (~1 before versus ~6 after) after practicing**. When looking just at those with little to no prior ID knowledge who solely used the app, novice-level app users (n=8) were able to correctly identify significantly more aquatic macroinvertebrates at the Order level[5] (~7 before versus ~16 specimens after), and at the Family level[6] (~0 before versus ~4 after)

[3] $t(19) = 4.90$, $p=.000$
[4] $t(19) = 3.70$, $p=.002$
[5] $t(7) = 5.37$, $p=.001$
[6] $t(7) = 2.99$, $p=.020$

after practicing. Intermediate-level users who solely used the app (n=6) were also able to correctly identify significantly more aquatic macroinvertebrates at the Order level[7] (~14 before versus ~17 specimens after) after practicing. However, further studies with larger sample sizes of novice- and intermediate-level users are needed to see if these trends based on prior knowledge level can be generalized.

FIGURE 14: THE POCKETMACRO APP AS A TOOL FOR INCREASING ACCURACY & DATA QUALITY



In comparing the digital app to the two print-based tools**, the app and flashcards were perceived as significantly better at supporting users' accuracy than the printed key** (see Table 7). There were no significant differences between the tools regarding their perceived ability to support increased data quality.

When comparing across the three study conditions, **there were no significant differences in accuracy at the Order level based on whether participants only used the PocketMacro App, only used the Flashcards and Dichotomous Key, or used both the print and digital tools.** Delving a bit deeper to focus specifically on novice-level participants (those who correctly identified 0-8 specimens at the Order level before exposure to the tools), we found that those who only practiced with the app identified significantly less specimens at the Order level afterwards than those who only practiced with the printed dichotomous key and flashcards or those who used both the

[7] $t(5) = 3.71$, $p=.014$

digital and print materials[8]. There were no significant differences between conditions regarding changes in their Order level accuracy when just looking at intermediate-level or just examining expert-level users. This finding seems to suggest that those newer to the identification process may benefit from using simpler tools containing limited information. However, it should be noted that the sample sizes within each knowledge condition are small (between 6-8 people per condition). Thus, a larger sample size is needed to determine whether the novice-specific differences are generalizable.

There were also no significant differences in accuracy at the Family level based on whether participants only used the PocketMacro App, only used the Flashcards and Dichotomous Key, or used both the print and digital tools.

Similarly, there were no significant differences between conditions regarding changes in Family level accuracy when just looking at novice-level, just focusing on intermediate-level, or just examining expert-level users. These findings suggest that practicing IDing to Family, regardless of whether the tool(s) used are print or digital, results in more accurate Family level identifications.

TABLE 7: COMPARING PRINT & DIGITAL TOOLS FOR INCREASING ACCURACY & DATA QUALITY

	PocketMacro App (n=41)	Printed Key (n=39-43)	Printed Flashcards (n=40-44)
Increased my accuracy in correctly identifying aquatic macroinvertebrates	4.44**	4.16**+	4.55+
Increased the quality of the data I feel I can report	4.30	4.33	4.42

** On a scale from 1 to 5, with 1 being, "Strongly Disagree," and 5 being, "Strongly Agree."*

*** Indicates a significant difference at the p<.05 level.*

+ Indicates a significant difference at the p<.05 level.

[8] F (2, 21) = 3.56, p =.05

The App Builds Confidence

Almost all app users (98%) agreed that using that app had increased their confidence in identifying aquatic macroinvertebrates (see Figure 15). Several participants attributed their newfound confidence to practicing with the PocketMacro app:

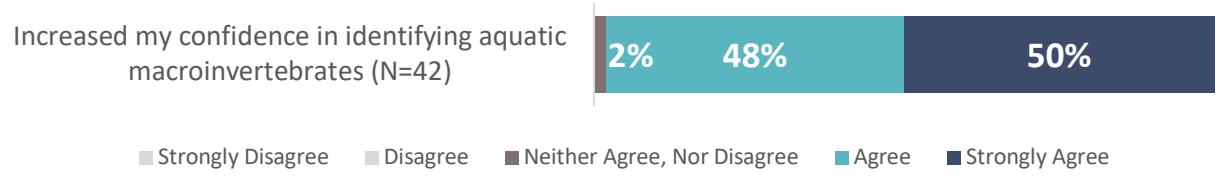
> *"The most useful thing for me was using the app to assure myself of my identifications and distinguish between bugs."* – Novice-level

> *"It was fun to learn a lot [using the app]. I feel more confident now when I go out in the field that not only do I know more now, but I'll be able to better identify things."* – Intermediate-level

> *"Overall, just the learning and becoming more confident [while using the app]. Especially at the Order level now, I feel like my confidence level with that identification has grown significantly."* – Expert-level

One novice-level app user noted that the increased functionality of iNaturalist (an app that identifies specimens based on a photograph), or having her ID confirmed by an expert entomologist would increase her confidence further. However, she also acknowledged that *"not having that feature forces me to learn more about them and try to become confident in identifying them myself rather than relying on the photo ID."*

FIGURE 15: THE POCKET MACRO APP AS A TOOL TO BUILD CONFIDENCE IN ID SKILLS



In comparing the digital app to the two print-based tools, **there were no significant differences in the tools' ability to build participants' confidence** (see Table 8).

TABLE 8: COMPARING PRINT & DIGITAL TOOLS FOR BUILDING CONFIDENCE IN ID SKILLS

	PocketMacro App (n=42)	Printed Key (n=44)	Printed Flashcards (n=45)
Increased my confidence in identifying aquatic macroinvertebrates	4.48	4.39	4.62

** On a scale from 1 to 5, with 1 being, "Strongly Disagree," and 5 being, "Strongly Agree."*

Some participants shared how they used the printed flashcards to confirm an ID:

> *"When I was IDing, just because it was a little bit different picture sometimes or maybe I was pretty sure I knew what I was looking at, I'd grab one of those cards like, 'Oh, okay. Yeah. Yeah, I was right,' instead of having to go through the app necessarily."* – Intermediate-level

> *"I really liked the flashcards. They were very helpful to me. I would lay them out and put them in the groups, and when I used the app and I found something, then I would confirm it with the flashcard."* – Intermediate-level

A few participants also indicated that they used the printed key as a confidence builder because they could view examples of multiple aquatic macroinvertebrates at once:

> *"I liked the confirmation in pictures of the many different types of mayflies and caddisflies. [Using the key] avoids the 'Wait, is that one too?' dynamic in the field."* – Intermediate-level

> *"I like having the option to follow the questions on the key as well as flipping it over to visually search for my specimen. By coming up with the same identification both ways, I feel very confident that I identified it correctly."*
> – Novice-level

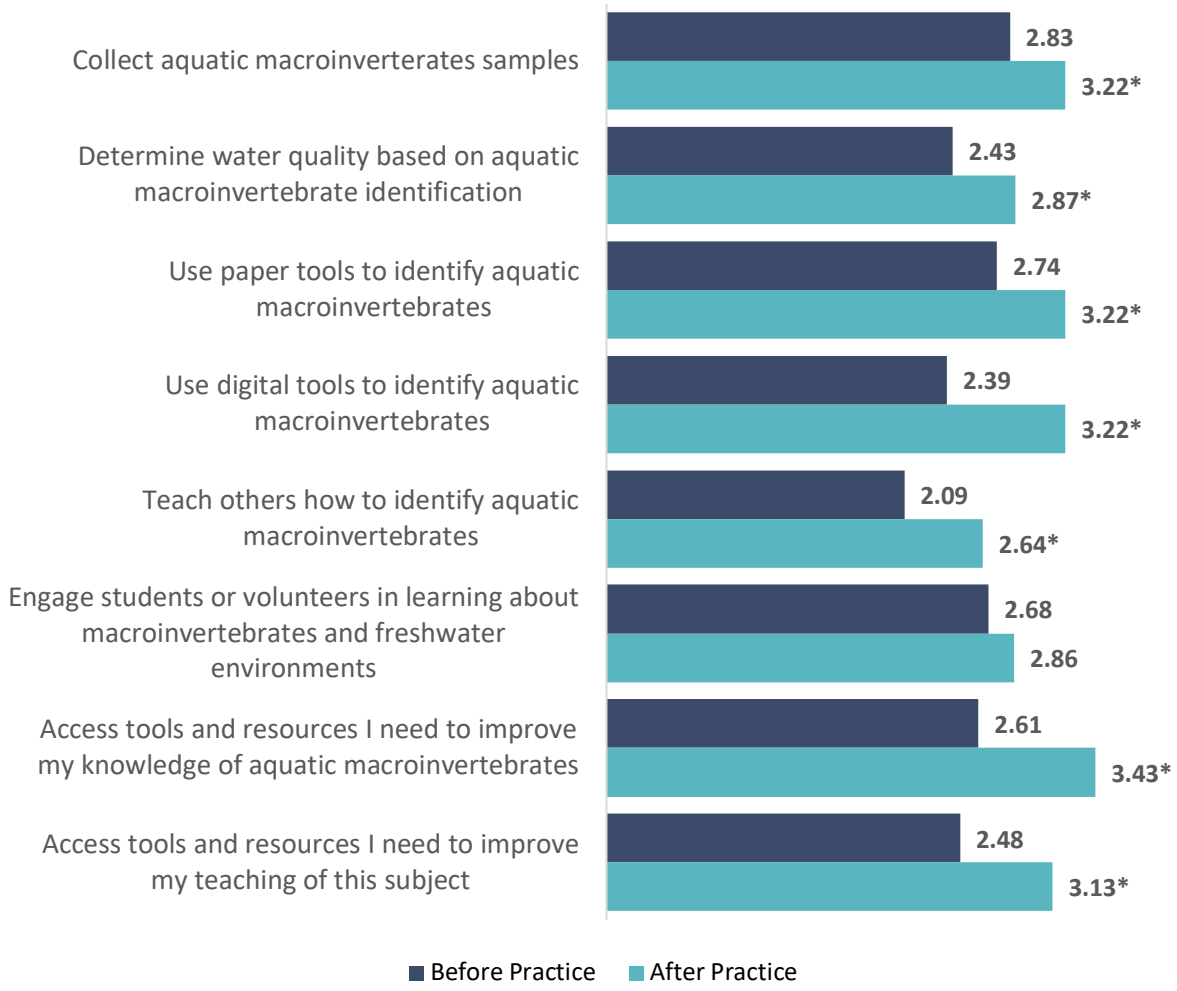
"Seeing an example of the different families [on the printed key] gives me great comfort when finding different varieties when collecting samples. It will cut down on second guessing." – Expert-level

Participants were also asked to indicate their level of confidence in conducting various activities related to aquatic macroinvertebrate identification. **Those who used both the print and the digital tools experienced significant increases in confidence in every category except for their confidence in engaging students in learning about aquatic macroinvertebrates** (see Figure 16). There were no significant differences between the three study conditions with the exception of one category – **Those who used both the print and digital tools were significantly more likely to experience an increase in confidence collecting aquatic macroinvertebrate samples than those who solely used the app or solely used the printed flashcards and dichotomous key.**

On an assessment where they were asked to rate their level of confidence in their identification of 21 different specimens before and after practicing with only the app as a tool, **app users (n=20) were significantly more confident in their Order[9] and Family level[10] after practicing**, regardless of whether they were novice-, intermediate-, or expert-level in their ID knowledge. Interestingly, **those who solely used the app also made significantly more attempts at identifying aquatic macroinvertebrates at the Family level after practicing with the app[11]** (~3 specimens before versus ~9 specimens after). When looking just at those with little to no prior ID knowledge who solely used the app, novice-level app users (n=8) made significantly more attempts to identify aquatic macroinvertebrates to Family after practicing with the app[12] (~1 before versus ~6 specimens after).

[9] $t(19) = 10.05$, $p=.000$
[10] $t(19) = 4.11$, $p=.002$
[11] $t(19) = 3.78$, $p=.001$
[12] $t(7) = 3.02$, $p=.019$

FIGURE 16: PRACTICE WITH A COMBINATION OF PRINT AND DIGITAL TOOLS INCREASED USERS' CONFIDENCE



* *Indicates a significant difference at the p<.05 level*

*** On a scale from 1 to 4, with 1 being, "Not at all Confident," and 4 being, "Very Confident."*

When comparing across the three study conditions, **there were no significant differences in participants' average increase in confidence specifically when IDing at the Order or Family levels based on whether participants only practiced with the PocketMacro App, only used the Flashcards and Dichotomous Key, or used both the print and digital tools.** Similarly, there were no significant differences

between conditions regarding changes in Order or Family level confidence when just looking at novice-level, just focusing on intermediate-level, or just examining expert-level users.

When comparing across the three study conditions, **there was also no significant difference in the number of specimens participants attempted to identify at the Family level based on study condition.** However, when focusing specifically on intermediate-level participants (those who correctly identified 9-15 specimens at the Order level before exposure to the tools), we found that those who only practiced with the app made significantly less attempts to identify a specimen at the Family level afterwards than those who only practiced with the printed dichotomous key and flashcards, or those who used both the digital and print materials[13]. Here, intermediate-level app users may have felt that they needed more practice before attempting to ID unknown specimens to Family. There were no significant differences between conditions regarding number of Family level ID attempts when just looking novice-level users or just examining expert-level users. It should be noted that the sample sizes within each knowledge condition are small (between 6-8 people per condition). Thus, a larger sample size is needed to determine whether the intermediate-level user-specific differences are generalizable.

The App Supports Educators And Trainers

The app appeared to support educators and trainers in teaching others about aquatic macroinvertebrates (see Figure 17). **Most users felt that the app was better than other tools they had come across in making aquatic macroinvertebrates accessible to others and for engaging students and volunteers** (81-82% of survey respondents agreed or strongly agreed that the app did so). One participant shared that the app's ability to read aloud to children supported those with lower literacy. Another user cautioned that any app might lead students to text their friends or explore other

[13] $F(2, 21) = 5.09$, $p = .02$

websites like YouTube instead of focusing on the lesson. Despite this, users cited the app's portability as something that made it easier for young learners to use:

> *"I think honestly [the app] was a lot easier to use than some of the resources we had been using. I know when I was teaching macroinvertebrates to kids before, I made up some binders that they had to flip through to be able to identify the macroinvertebrates that they were finding...I think that digital key that walks you through step-by-step, you can't really get lost in."* – Intermediate-level

Several users (71%) thought that the app would enhance their program offerings:

> *"This [app] just seemed like a great opportunity to be able to kind of solidify some of my own ID skills and taxonomy knowledge, but also be able to recommend this tool for others that go through our workshops for our stream monitoring because macroinvertebrate identification is a big chunk of the curriculum for that. There's always questions in our workshops of resources out there to learn more, and I think having this app and this resource is something that I can pass along to workshop participants to help their knowledge increase as well."* – Expert-level

> *"The group I work with, we do stream monitoring...so it's very handy to be able to know what I'm looking at when I'm out in the field without having to bring too many materials with me. I also do a lot of work with young students, fifth graders usually, and I teach them about macroinvertebrates and their importance for water quality."* – Novice-level

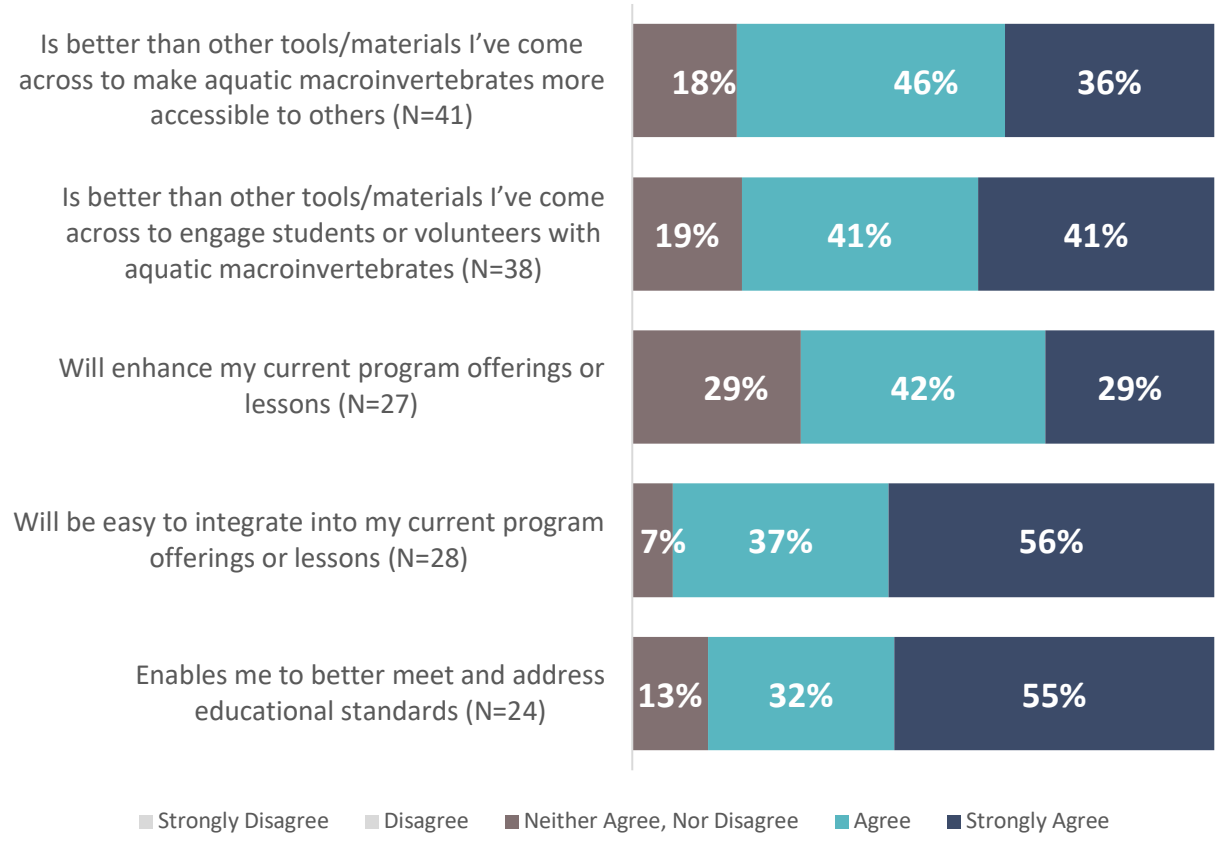
Many users (91%) indicated that the app would be easy to integrate into their lessons:

> *"I think I would definitely could use it out in the field when I'm working with larger groups of students because I could put it on my iPad and I could, and more children could see it at the same time versus the guide where the pictures are very small and we have to really crowd around it to look at it."* – Novice-level

"When I'm learning different things to teach them or putting together like a PowerPoint or something to teach them different things, I might pull some information from [the app] out." – Intermediate-level

Users (87%) also thought that the app would help them address educational standards. In exploring differences by participants' prior knowledge, intermediate- and expert-level participants were significantly more likely to feel that the app is better for engaging students and volunteers than novice-level users[14]. This is likely because novice-level users are still learning themselves, and may not be teaching others at this stage.

FIGURE 17: THE POCKETMACRO APP AS A TOOL TO SUPPORT EDUCATORS



[14] (F(2, 37) = 4.49, p=.018

In comparing the digital app to the two print-based tools, **the app was seen as being significantly better than other tools at supporting accessibility and student engagement than the printed key** (see Table 9):

> *"I think when you're teaching younger kids or high school students who don't have any experience in macroinvertebrates, I think the other resources [flashcards and app] would be more useful just because I think that they could get caught up, and not essentially being able to follow the key properly because they don't understand the components that make up a macroinvertebrate such as the legs or the segments or the thorax - the different vocabulary that goes with them. So I think that can make it harder for them to use the key."* - Intermediate
>
> *"When we do classification we're trying to teach them how to use a [printed] key, but they'll often just look at the pictures instead of going through the process of choosing one answer over another and working their way through the key...I think [the app is] a lot more interesting than for the kids to have to go through a dichotomous key. The pictures are interesting and you can point out things - just not compare side to side - but you can kind of flip from one to the other and show differences...Just because it's an app that makes it a lot more attractive to kids."* – Expert-level

There were no significant differences between the tools regarding their perceived ability to be integrated into or enhance lessons, or to address educational standards.

Study participants were also asked whether the various digital or print resources would be useful to them in the future for helping others learn about aquatic macroinvertebrates. **Most app users (95%) thought that the PocketMacro app would be useful for helping others learn about macroinvertebrates in the future** (see Figure 18). **There were no significant differences between the digital and print tools regarding their perceived usefulness in helping others to learn about aquatic macroinvertebrates** – all three resources were seen as useful for this purpose (see Table 10).

TABLE 9: COMPARING PRINT & DIGITAL TOOLS ABILITY TO SUPPORT EDUCATORS

	PocketMacro App (n=24-41)	Printed Key (n=19-43)	Printed Flashcards (n=19-43)
Will be easy to integrate into my current program offerings or lessons	4.18	4.37	4.41
Will enhance my current program offerings or lessons	4.22	4.35	4.46
Enables me to better meet and address educational standards	4.00	4.05	4.32
Is better than other tools/materials I've come across to make aquatic macroinvertebrates more accessible to others	4.49**	4.09**	4.33
Is better than other tools/materials I've come across to engage students and volunteers with aquatic macroinvertebrates	4.42**	3.98**	4.28

** On a scale from 1 to 5, with 1 being, "Strongly Disagree," and 5 being, "Strongly Agree."*

*** Indicates a significant difference at the p<.05 level.*

+ Indicates a significant difference at the p<.05 level.

FIGURE 18: USEFULNESS OF THE POCKETMACRO APP TO HELP OTHERS LEARN ABOUT MACROINVERTEBRATES IN THE FUTURE (N=41)

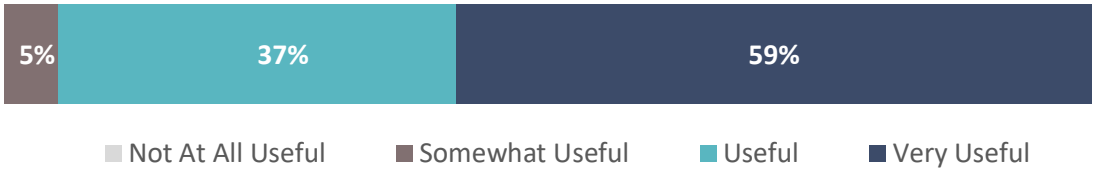


TABLE 1O: COMPARING PRINT & DIGITAL TOOLS USEFULNESS IN HELPING OTHERS LEARN ABOUT MACROINVERTEBRATES

	PocketMacro App (n=41)	Printed Key (n=43)	Printed Flashcards (n=43)
In the Future	3.54	3.58	3.70

** On a scale from 1 to 4, with 1 being, "Not at all Useful," and 4 being, "Very Useful."*

AFFORDANCES OF DIGITAL RESOURCES

AFFORDANCES OF THE POCKETMACRO APP

Users liked that the app could be conveniently accessed on their mobile devices:

> *"It's an easy and convenient way to study...People have their phones on them pretty much constantly anymore...You didn't have to carry around any paper things or whatever."* – Intermediate-level

> *"I think most of it was just that the convenience of [the app], that it's like in my pocket the whole entire time and if I have free time, I can just do that instead of having other like multiple physical things out."* – Novice-level

> *"On the move and mobile - using [the app] while on the creek is very handy. It also works offline which is huge because when doing surveys of streams…I don't always have the best cell signal."* – Novice-level

However, a few users were worried about damaging their technology. One novice-level participant cautioned, *"[A laminated key is] a tangible thing you can hold...I don't want to drop my phone in the stream when I'm sampling."*

Users appreciated the quality and variety of images available in the app, and the zoom functionality allowing them to see specific features closely:

> *"[The app has] high quality photos and great descriptions of the body parts and what they are used for."* – Novice-level

> *"[The app] was so easy to navigate, see images, and learn about distinguishing characteristics. I loved the way the images fill my phone screen."*
> – Intermediate-level

Users also liked the amount of information provided within the app, specifically that was all packaged within the same tool:

"Even though I do like the printed tools, I like the app because it just has all the information from the flashcards, the information from the key, and then it has even more information." – Expert-level

"I like that it gives the user several options of learning. You can use the Key, flashcards, look at each Order, etc. It is very easy to understand and use. I also think the app design makes me want to use it more. I really enjoy using the app overall." – Intermediate-level

Opinions About the PocketMacro App's Specific Features

Survey respondents found the three sections of the PocketMacro app to be helpful overall, with the Field Guide rated most highly, followed by the ID Help and Flashcards (see Figure 19). Those with intermediate- or expert-level prior knowledge rated the Flashcards as significantly more helpful than novice-level participants, suggesting that some prior knowledge is needed to effectively utilize this feature[15]. However, there were no other significant differences regarding the app's specific features based on users' prior knowledge.

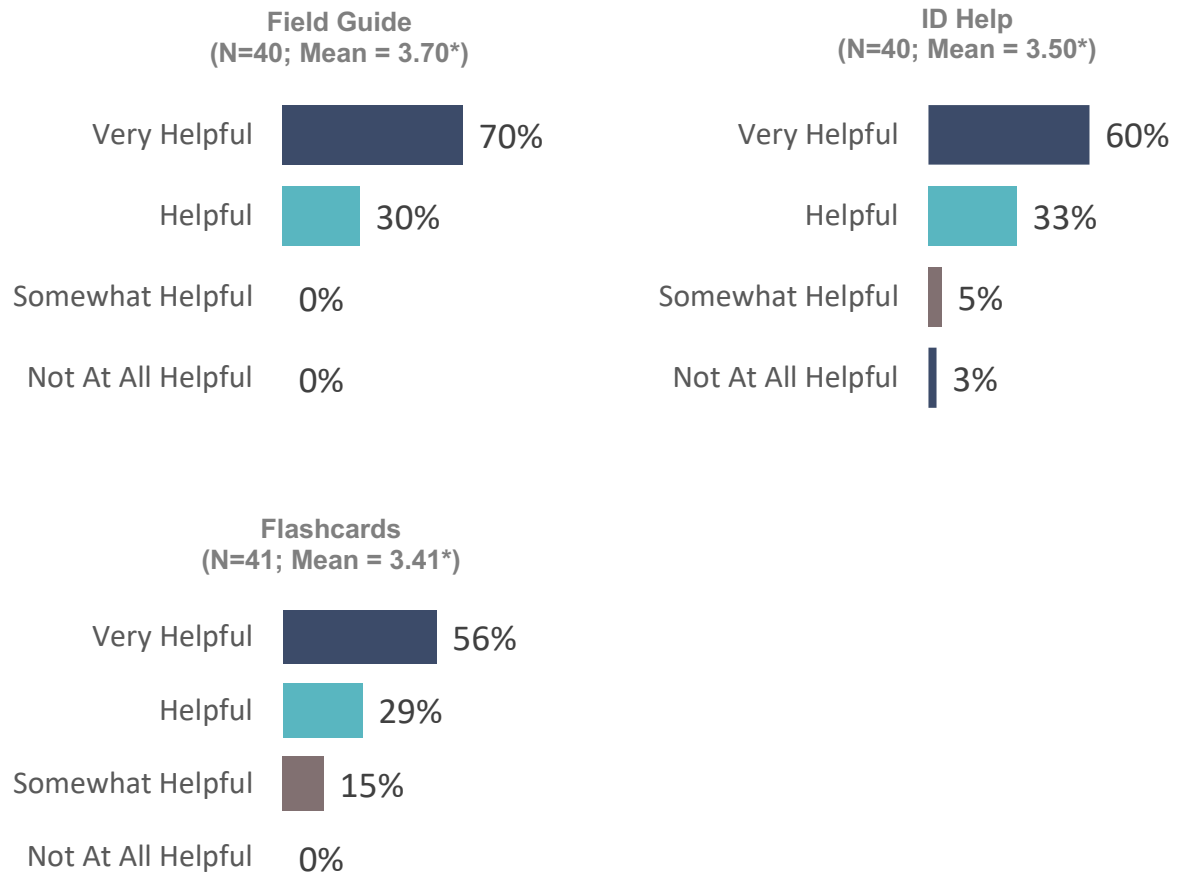
Two app users summarized what they liked best about the PocketMacro app's features:

"The features within the app were very helpful to me. Both the ID key, being able to use the flow chart on the app and be able to get into more detail than what I could get into on the printed ID key. The field guide was super helpful to look at the information for each Order, like the features and then to get into the Family level because for me, I just was hoping I could get the Orders. To get down to the Family level, that's much more challenging for me. But the fact that that information was there was helpful. The flashcards were awesome, and I used those to practice. So, yeah. I mean each of the features was very helpful."
– Intermediate-level

[15] $F(2,40) = 4.33$, $p=.020$

"The ID key is helpful and more user friendly for beginners than using an actual [printed] key. The Field Guide also contains a lot of useful information."
– Expert-level

FIGURE 19: HELPFULNESS OF POCKETMACRO APP SECTIONS - FIELD GUIDE, ID HELP, FLASHCARDS



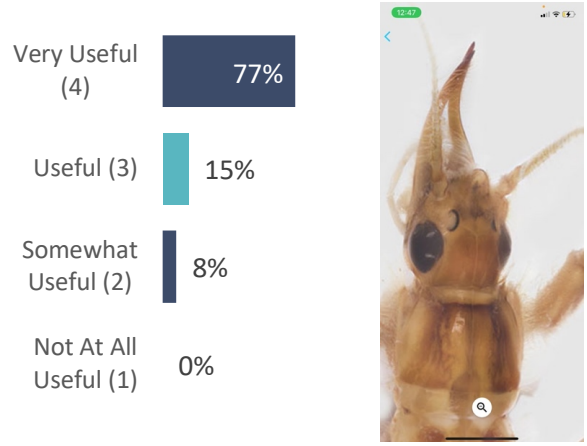
** On a scale from 1 to 4, with 1 being, "Not At All Helpful," and 4 being, "Very Helpful"*

Thoughts About the Field Guide Section

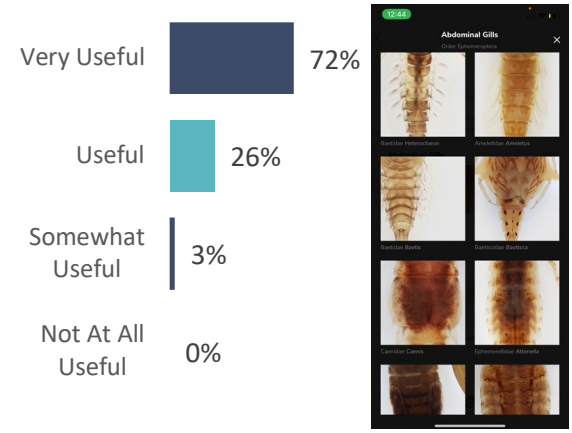
Attendees were specifically asked to reflect on the usefulness of the Field Guide section's various features. The Order and Family level lists of diagnostic features were deemed to be the most useful aspect of the Field Guide (see Figure 20).

FIGURE 20: USEFULNESS OF THE FIELD GUIDE FEATURES

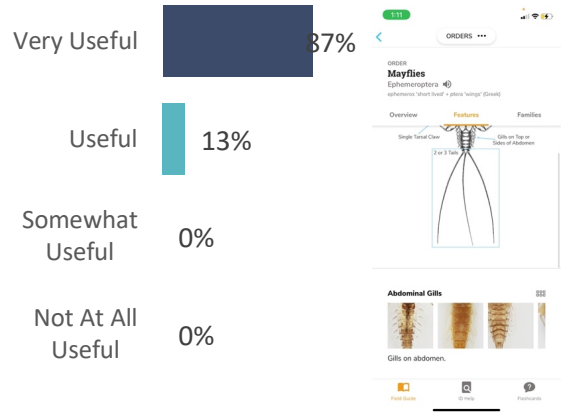
Zoomable Macroinvertebrate Photographs (N=39; Mean=3.69*)



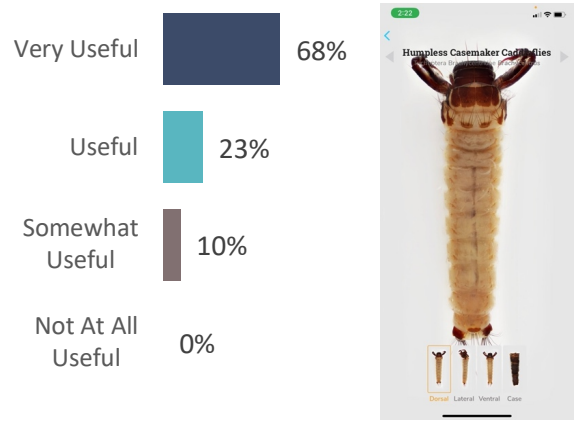
Gallery of Diagnostic Features (Order/Family) (N=39; Mean=3.69*)



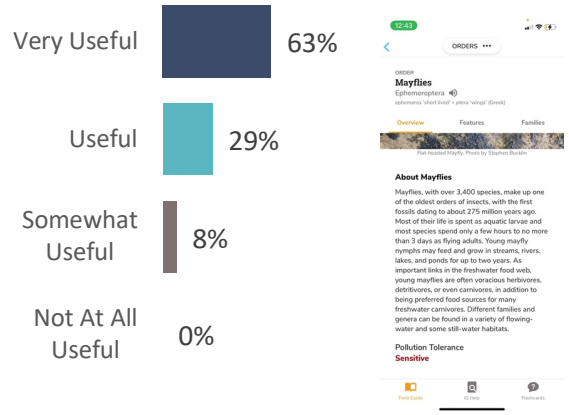
Diagnostic Features (Order/Family) (N=39; Mean=3.87*)



Flip Views (Dorsal/Ventral/Lateral) (N=40; Mean=3.57*)



Pollution Tolerance Information
(N=38; Mean=3.55*)



** On a scale from 1 to 4, with 1 being, "Not At All Useful," and 4 being, "Very Useful"*

App users described their favorite aspects of the Field Guide section:

> *"It is very user friendly and set up well. I like how the Field Guide has each Order with an overview, detailed look at the Order's characteristics, and pictures/description of each Family. The Features section does a really good job of showing close-up examples of the different characteristics to look at that identify the Order/Family. I like how the descriptions use technical terms, but also explain what they mean (i.e., sclerotized)."* – Expert-level

> *"[The Field Guide] kind of gave you more information about that particular Family of organisms...It helped you kind of appreciate them more and figure out their function in different things, which can help you relate it to identification. Like if you realize, 'Oh, this organism feeds on this. It makes sense that it has this type of a mouth,' or different things like that."* – Intermediate-level

"The part that I used the most was the Field Guide. I really liked that it broke up all of the insects into those categories of the Orders and that it has a picture with it. And so that kind of leads me in the right direction immediately. I'm like, 'Okay, this is a Diptera.'" – Novice-level

Thoughts About the ID Help Section

The ID Key Results Page was thought to be the most useful specific feature of the ID Help section (see Figure 21). **Most app users liked the organization of the ID key by specific features' questions**:

"The ID Key- using the questions to narrow down what you are looking at." – Intermediate-level

"The ease of use, and the ability to go back if you seem to have made a mistake...I love Dichotomous Guides...I was always a big fan of the 'Choose Your Own Adventure' stories as a kid. So it kind of feels like that, but I really liked that it had pictures that showed examples, and I also liked that you could click on things and it would tell you what that was. So for example, like the first question here is like, 'Are there joint legs?' and it would click to tell you what a jointed leg was. That's helpful again because sometimes things get kind of into the nitty gritty in terms of jargon and it's helpful for people who may not have that to be able to explore a little bit more." – Novice-level

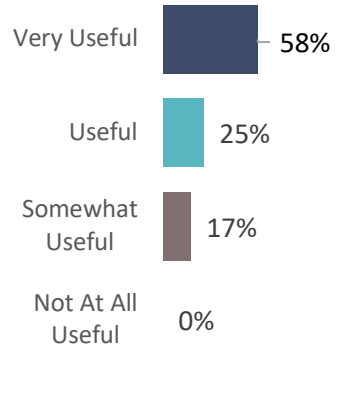
"In general, the way a dichotomous key is laid out, where it's very simple. You just answer one question at a time, 'A or B?' and you just kind of work your way through. So I was happy to see that added in this tool as well." – Expert-level

However, a few app users found it difficult to make an identification if they misidentified a feature:

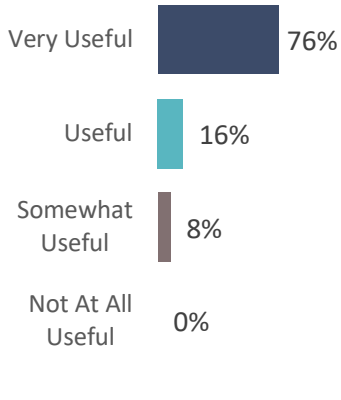
"I thought the ID key would be my favorite part, but actually that was my least favorite part...You know how on the dichotomous key, the paper ones, you can kind of see ahead and it helps you understand like which macroinvertebrates you could possibly be going towards? If you make a wrong answer here, you can get in the wrong direction completely. So if I goof on the first question, then the whole thing is kind of - I ended the wrong place no matter what." – Novice-level

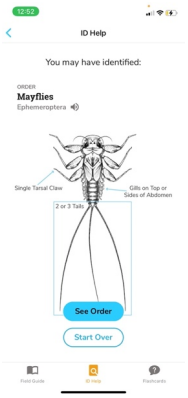
FIGURE 21: USEFULNESS OF THE ID HELP FEATURES

Zoomable ID Key
(N=24; Mean=3.42*)

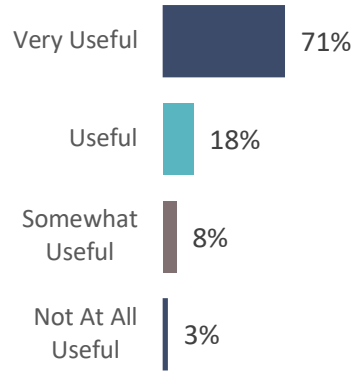


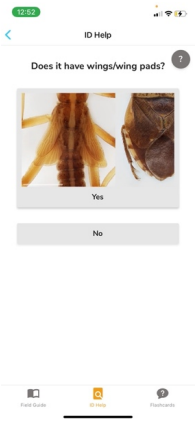
ID Key Result Page
(N=38; Mean=3.68*)





Guided Dichotomous Key Questions
(N=38; Mean=3.58*)





** On a scale from 1 to 4, with 1 being, "Not At All Useful," and 4 being, "Very Useful"*

Thoughts About the Flashcard Section

App users who liked the flashcard section of the PocketMacro app liked using them as a tool to study diagnostic characteristics and check their aquatic macroinvertebrates' ID knowledge:

> *"[I used] the flashcards [in the app] to test myself on my identifying skills."* – Novice-level

> *"I liked that it had the flashcard feature. I thought that was helpful. As you're learning them you can go through and tell yourself like, 'Oh, I think it's this,' and then flip the card over and figure out what it actually is."* – Intermediate-level

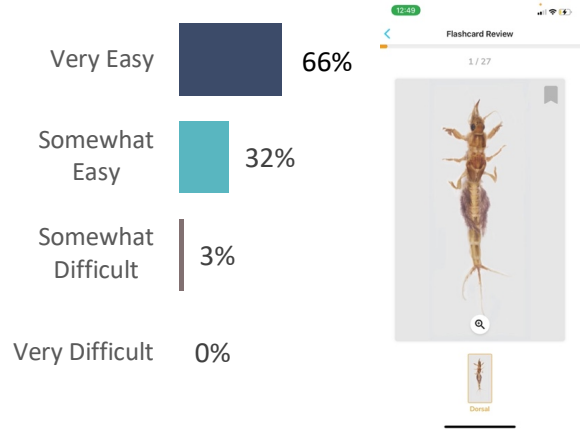
> *"I liked how you could go through the flashcards and kind of quiz yourself on them. I think the kids enjoyed doing that too...There's arrows on there and just, I guess, repetition. Just going through the flashcards and trying to figure out from the distinguishing characteristics which Order they were in...The flashcards were a way to identify trends in characteristics of each Order. It was much easier (with the awesome pictures) to learn these trends."* – Expert-level

> *"The flashcards with their 'look-alike' section was the most helpful. It helped increase my confidence in the identifications."* – Intermediate-level

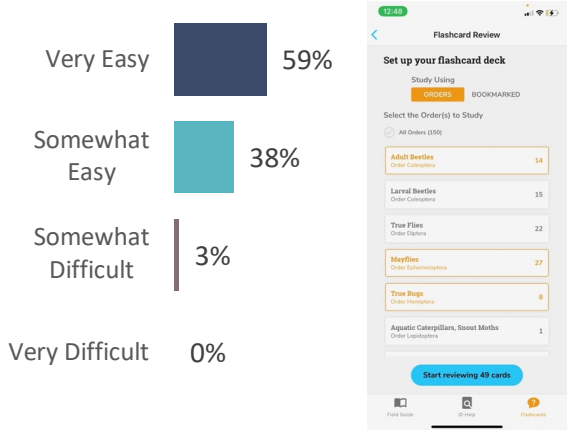
Survey respondents were asked to rate how easy two of the Flashcard sections' features were to use, and whether they would utilize two other features in the future. Respondents found the flipping, swiping, and zooming functionality slightly easier to use than the set-up functionality (see Figure 22). Most were likely to use the Family level "See More" feature (74%) and the Bookmark feature (69%) in the future.

FIGURE 22: EASE OF USE OF THE FLASHCARD FEATURES

Flipping, Swiping, Zooming Functionality (N=38; Mean=3.63*)



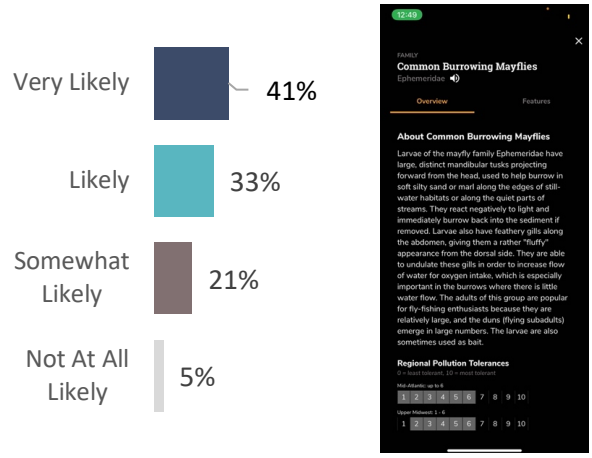
Flashcard Set-up Functionality (N=34; Mean=3.56*)



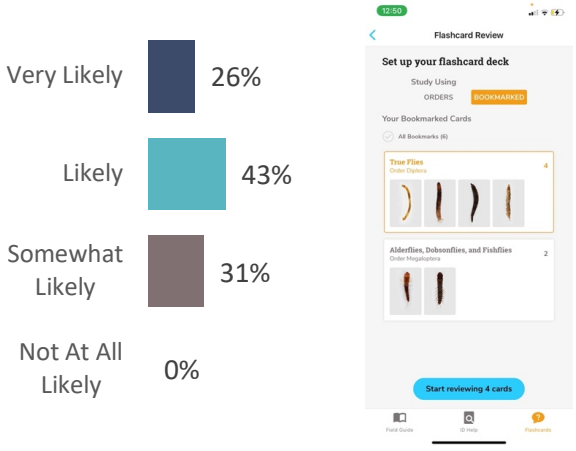
** On a scale from 1 to 4, with 1 being, "Very Difficult," and 4 being, "Very Easy"*

FIGURE 23: LIKELIHOOD OF FUTURE USE OF THE FLASHCARD FEATURES

Family Level "See More" Feature (N=39; Mean=3.10*)



Flashcard Bookmark Feature (N=35; Mean=2.94*)



** On a scale from 1 to 4, with 1 being, "Not at all Likely," and 4 being, "Very Likely"*

Recommendations For Improvements to the PocketMacro App

App users had a few suggestions of ways to improve the app in the future. Several participants mentioned that when they clicked on an image or icon, they were kicked off of that page in the app. Some shared specific challenges they have in doing aquatic macroinvertebrates identification that they wanted the app to address. For example, one user noted that branched gills are hard to see on different organisms, making it difficult to answer whether they are present or not in a dichotomous key. Another wanted *"examples showing how to count the abdomen segments or leg segments...Particularly the abdomen would be helpful to know where it begins and ends.*" One user specifically sought labels for the air straps on the Belostomatidae: *"I know they are at the apex of the abdomen and I have been zoomed in automatically by the app, but it's still not super clear what to look for."* Others asked for more representation of desiccated macroinvertebrates, Northeastern specimens, snails (lunged, gilled, right, left), and non-insect organisms such as leeches, clams, and mussels. These comments generally referenced the visual image quality and ways imagery could be improved or annotated more precisely.

App users had recommendations for each of the app's specific sections as well. In terms of the Flashcards section, a few app users mentioned that trying to click on the pronunciation icon made them exit out of the screen they were on: *"It was a little sensitive and it would flip the card back over rather than press on the actual audio feature."* Similarly, some users noted that the flashcards reshuffled when they exited that section, and they had thought they would stay in the same order. A few users suggested having more flashcards in general or to include a *"Quizlet-type"* set of flashcards of common characteristics: *"I wish there were more flashcards and more ways to quiz yourself. I feel I learn better that way".* Another said, *"Maybe have a 'hint' button on the flashcards where marks or arrows highlight the actual distinguishing features of that order on the photo, so students can learn the subtle differences, like lack of legs on Diptera, or lateral filaments on Megaloptera."* Some users wanted more customizability. For example, *"I wished, when bookmarking the macroinvertebrates, we*

could put 'two strikes' or 'three strikes' on the ones I kept most commonly missing, so I would see them more often or could do only those I missed most often."

In terms of the Field Guide section, despite the presence of a glossary, novice users wanted more introductory materials to describe terminology:

> *"I also believe that when first using the app and as a beginner with bugs, I didn't know where to start or what anything meant (ex., Family, Order, species)."*
>
> *"I also would like the ability to click on key words for a quick description/definition. I am just learning the "language" of macroinvertebrates."*

One user found it challenging to compare specimens to one another in the Field Guide stating, *"It would be nice to be able to compare them like in the 'look-alikes review,' but be able to pick which ones to compare. The images used are great, but it could be nice to use more for a single Family to show variations you could see within the Family."* Another shared that she didn't have a good sense of the actual size of the insects.

For the ID Key section, users noted that printed keys allow you to see all of the potential feature options and Orders at once, whereas the key in the app goes one question at a time. Some also sought more definitions regarding the diagnostic features to support the identification process, wondering if there was a way to toggle between the flashcards and the key:

> *"If there'd be a way to, when you're using a key, maybe incorporate some of the definitions that were present on like the flashcards, like the introductory section of the flashcards. How they said, 'When we're referring to this term, this is what it means...It's asking you to identify it has this many body segments. If you could maybe define or give an example of what that is on the same page as the question that could maybe be helpful for somebody who's not super familiar with them and really just starting to learn them."*

Several users requested Family-level keys, especially for EPTs: *“Descriptive features for families are ‘tucked’ away when they could be placed into a button-based dichotomous key.”* Two users indicated that they thought one of the specimens, a snail, was mislabeled: *“There was one I noticed for snails. I had trouble, because I couldn't get as much detail as I wanted...But I know that certain like left-handed snails and right-handed snails have different tolerances sometimes.”*

App users also proposed potential new features that they thought would enhance the experience. Some of these were related to functionality: *“I thought the arrows under the Settings page would lead me to another page, but I instead accidentally reset a few things. It would be helpful if these were toggle switches instead.”* Others were related to preferences for learning. For example, users suggested adding filters, a notes feature, photo recognition, and a fill-in feature:

> *“I'm just like a person who likes physical things and learning from physical things, writing them down. It would be cool to have like a little notes section in the app and write down notes about a certain species or things to look out for.”*
>
> *“Have you used iNaturalist? The photo feature on that is really nice, being able to take a photo of something and get suggestions for what it might be.”*
>
> *“If there was like a search function that you could put into like, ‘Oh, it has this segmented body or this many filaments or tails. If there was like a filter, I guess...and it could give me possible Genuses after that.”*
>
> “Although this app did a great job at describing the pictures and species identified, it was still a game of memorization. I don’t feel like I know the names confidently, I just could pick them out if listed. A fill-in feature would be helpful to make sure we are fully understanding the insect Order names.”

AFFORDANCES OF PRINT RESOURCES

AFFORDANCES OF THE PRINTED DICHOTOMOUS KEY AND FULL COLLECTION VIEW LAMINATED POSTER

Participants who used the printed poster appreciated that the tool allowed them to see multiple Orders at a glance on the side with the full collection view (see Figure 24):

> *"I like all the pictures. That made it very easy for me to see actual – because, you know, the different colors can change a lot between different species or Orders and Families and things...It does make it easier for people who are new to it if they're finding things that are slightly similar. But again, seeing those differences in that variation. For example, like the mayflies. There's so many different shapes for the mayflies that you may not see again based on the typical drawings that you would normally just get...With the beetles especially, I liked that there is pictures of their larval stages as well as their adult stages because you don't usually see that on other guides."* – Novice-level

> *"I think the chart showing the wide swath of diversity across Orders on the back."* – Intermediate-level

> *"It was useful to have pictures of all of the different macros (and their cases) one might encounter in the region."* – Expert-level

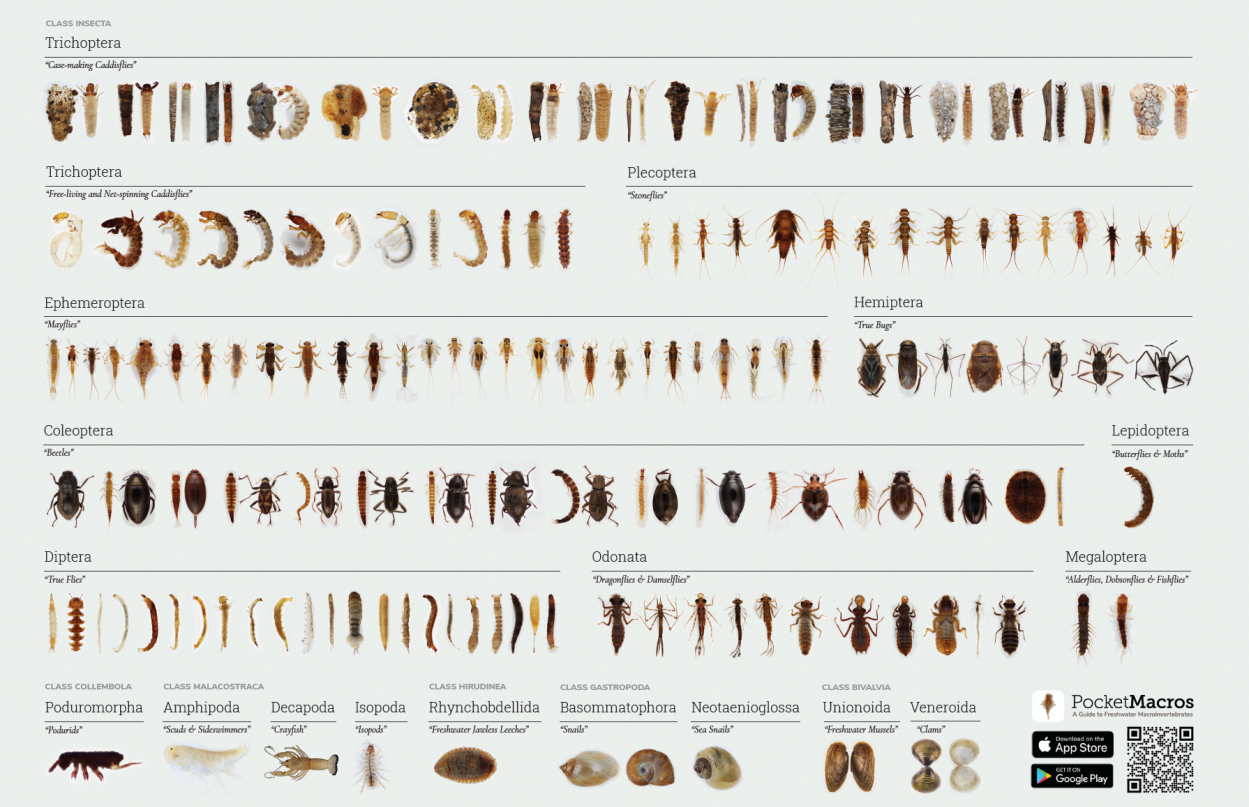
> *"All of the organisms are on there in once glance!"* – Expert-level

A few participants liked the information and imagery presented in the full collection view, and used it to confirm an ID or to figure out relationships between different organisms:

> *"I like the size of it, and to just kind of like have that up while I was studying everything. So that way if I was going through the flashcards and then I thought, 'Well how is this related to a different macro, then I could look on the key and see where it was."* – Novice-level

"I thought it was helpful that on the reverse side it gave you all of the different images of them because as you worked your way down through the key and you got to the final answer, you could flip it over and look and see, 'Oh, do I really think that this is what this is? Maybe I made a mistake somewhere throughout.' So I think it helped to double check yourself, and make sure that the characteristics you identified working your way through the key was correct."
– Intermediate-level

FIGURE 24: SCREENSHOT OF THE FULL COLLECTION VIEW LAMINATED POSTER



One expert-level user *"[liked] seeing the different paths that lead to the same Orders"* on the key side of the printed poster. Yet another expert-level participant cautioned that when Orders appeared in different places, it might confuse users: *"The key was a useful way to highlight meaningful differences between the Orders, but could be a bit*

confusing when the same Order was present multiple times. So, good as a top-down ID system, but not as good as a study tool for remembering the features of each Order."

Participants also liked the organization of the printed key into feature-based questions:

> *"That was the easiest and quickest Identification key I have ever used. When working down the easy-to-use steps, you arrived very quickly at the correct Family and felt very confident in your conclusion. Key questions were very clear and unambiguous."* – Expert-level

> *"I liked the flow chart on the app, but you know, you're only seeing one step at a time. So having the whole flow chart visible and being able to work through it was helpful...Obviously it doesn't have the level of detail, so sometimes it was insufficient for me because I didn't have enough knowledge to work through and get the right answer...whether or not it had a case...that was such a distinguishing feature that that separated out what the options were pretty clearly...Even just at the outset with the jointed legs, like the number of legs, then [the key] sent you in the appropriate direction."* – Intermediate-level

> *"It helps to outline and walk you through how to identify them. Like, 'Oh, this organism has this many legs or this one has this many, or this many tails. Or this one has cases, this one doesn't. It just helps kind of outline the differences between two...It helps you kind of get down a path as to what could be the correct answer."* – Intermediate-level

> *"It's good to understand how they differ from each Order and what makes them different. Like this one has one tarsal claw, this one has two, and kind of take you through the steps of identifying."* – Expert-level

A few users had difficulty making a correct identification using the features-based questions in the printed key:

"I had one problem where I was using the [flash]cards to pick random macroinvertebrates to key out, but I kept struggling with keying out members of the Odonata Order. I knew that I was keying out a damselfly nymph (because I was using the cards), but I kept answering the questions incorrectly and ended up with caddisfly several times. I wasn't sure which question(s) I was answering incorrectly." – Intermediate-level

Some liked the printed key better than the app because they thought it might be more useful in the field:

"I think it might be more useful than your phone in the field because not everywhere has like internet service or if your phone dies then you would have that and it's laminated so it won't get wet." – Novice-level

"It is more detailed than other keys that I've used. It fits onto one page and gets you through the dichotomous key without having to flip through a book. I also like that it is laminated. I will be able to bring it into the field for live identification with students. I already am pretty strong at identifying to Order, so the key did not provide much new information to me." – Intermediate-level

However, others participants felt that the dichotomous key in the app was better. Another novice-level user shared, *"I don't like the [printed] key. It doesn't flow well to me. [It's] confusing. I know it is the same as on the app, but the app is easier to key."* **A few noted that the printed key was not helpful for Family-level identification.** Some viewed the key as cumbersome and "*something else to carry when on the creek."*

The main constraint that users noted was that the images used in the printed key were small:

"For a beginner I think it's hard to use the key because the pictures are so small." – Novice-level

“The pictures are very teeny tiny on it. Again, you can't zoom in on those. So while it was helpful, you know, for something I was pretty confident on, if I didn't have a clue, it wasn't helping a whole lot because you really couldn't hold it up to your eye...I had difficulty with the caddisfly and the true fly larvae...the little work looking guys...It said something that had the little hook on the tail...We can’t see that really on the chart.” – Intermediate-level

“I did not know the difference between a wing pad and wing, and found whether the creature had these or not was difficult to distinguish from the images on the key or the flashcards. The gills, on the other hand, were shown to me by careful examination of the flashcards and the key. The [water] penny larva and the Dobsonfly larva were in the key as having six legs, but I could not see any legs on the larva. That made it difficult to identify them using the key.” – Novice-level

“It’s difficult to see organisms up close on the key. If you’re using this key, you have to understand the terms to correctly ID.” – Intermediate-level

“[It was] hard to see lateral filaments and some details [on the printed key].” – Novice-level

“You can’t always count the amount of legs in the photos.” – Novice-level

Some additional challenges with the printed key included learning the vocabulary and how to pronounce terms:

“[I] had to look up some terminology (portable case).” – Novice-level

“*Just some type of definition when you're working your way through or like a little box in the bottom corner or something that says the different terms that are used throughout the key that somebody might not be familiar with just to help them.”* – Intermediate-level

"The wording on the key was different from what I have used in the past. So it was hard for me to follow along." – Novice-level

Recommendations For Improvements to the Printed Key and Full Collection View Laminated Poster

The main recommendation participants had to improve the printed key and poster was to include more information. Specifically, they mentioned things like including a summary list of the macroinvertebrates highlighted on the key, sharing their common names, pollution tolerance levels, and descriptive features:

"It would be helpful to have a separate list/key of all the macros pictured on the key."

"I'm not a fan of the backside not having the names of the macros. Since they are smaller and printed, the photos are not as easy to see, so having the names labeled would be nice."

"It would be nice if the side with various photos for each Order also listed the Family and/or common names below the pictures. Having all (or at least some of the most common) Family and/or common names and photos on the dichotomous key side would be helpful. Many within the same Order look very different."

"Adding a diagram of anatomy similar to that found in the Flashcards [would be useful]."

Participants also suggested changes to the look and feel of the key, namely color-coding and non-glare lamination:

"I think it would help if the arrow pathways were maybe like color-coded."

"Maybe shade every other Coleoptera larva beetle pair to distinguish what goes together easier. It starts with a beetle, but then the next two pictures look like

they are supposed to be together. Then at the end of the row there are two larvae."

"Plastic protection needs to be non-glare for outdoor use."

Affordances of the Printed Flashcard Deck

Participants appreciated that the flashcards were a powerful, accessible tool for studying:

"I like the compact size. I was able to carry them around in my pocket and practice when I was on my downtime from work or waiting to go somewhere. The little facts are nice to learn. I also liked having both a drawing and a photo."
– Intermediate-level

However, some users were unsure whether the flashcards were portable enough:

"The only drawback I would say is to ID them out in the field. Like you're not going to want to have to bring a pack of cards with you and then like dig through them all. Especially if you're in a pond or in a stream, [you] don't wan't to drop them in there." – Novice-level

"Once you got them all spread out on your desks, they're taking up a lot of space, and you're trying to [determine]...'Is it this group or is it this group?' And then you're flipping through. They weren't as convenient as the app of course."
– Intermediate-level

Many users reported sorting the cards into piles based on Order or pollution sensitivity. One user placed the flashcards in a binder sorted by pollution tolerance to study them. A novice-level user tried playing a matching game based on just the images, attempting to place different specimen cards in their correct Order piles. He shared, *"I think it goes back to me just liking physical things in my hand."* Another intermediate-level user decided to focus on the ones she did not have memorized consistently: *"I looked for leg,*

tail, shape patterns to associate similar macros. I sorted them according to 'I know' and 'I don't know,' and then looked on the back to reinforce the names." A different intermediate-level user discussed potential applications with young learners: *"Depending on what age group I'm dealing with...we could do some games...Maybe I'll set out some samples from the creek and then give them ten cards and they've got to match them up."* Users in the print-only condition did not use the QR codes on the flashcards because they were explicitly instructed not to do so during the study. However, a few did note their presence and were interested in utilizing them in the future.

Several flashcard users liked the variety of macroinvertebrates represented, which allowed them to explore the differences between Orders often by placing the cards side-by-side:

> *"The photos are very good quality with evident details, and more than one EPT was represented as a great comparison."* – Expert-level

> *"It's just repetitive, you know, just repeat and repeat and repeat. I like that it has different types of mayflies, or different types of snails, so that you can really start to learn those smaller differences."* – Novice-level

> *"The pictures were large enough that I could see them. The Order card itself had the distinguishing features, so I would use that as well. The compare and contrast by being able to lay them out next to one another - I could compare and contrast more easily than on the app where you'd have to go back and forth...I could put them right next to one another and see the number of tails, the filaments, whether or not there were pro legs."* – Intermediate-level

Users liked the engaging way that the images and facts about each macroinvertebrate were presented on the flashcards:

> *"Simple and sleek with a touch of whimsy with the illustrations."* – Expert-level

“I like the fun way the story about each creature is told in first person. It is engaging and often humorous, so I am interested and maybe will even remember some details for next time.” – Novice-level

“I love having flashcards that I can take anywhere with me. The information on the flashcards is very accessible and the artist’s rendition of each Order is fun!” – Intermediate-level

“It feels professional and nice, but I also like that it was kind of cutesy because they have a picture on one side with like a little speech bubble and then actual pictures of them with different views of them as well...The more cartoon pictures, I think that makes it more accessible to younger folks who are starting to learn about it. Like my son would really find those pictures fun and cute, where like the pictures of the bugs might be a little bit intimidating to him.” – Novice-level

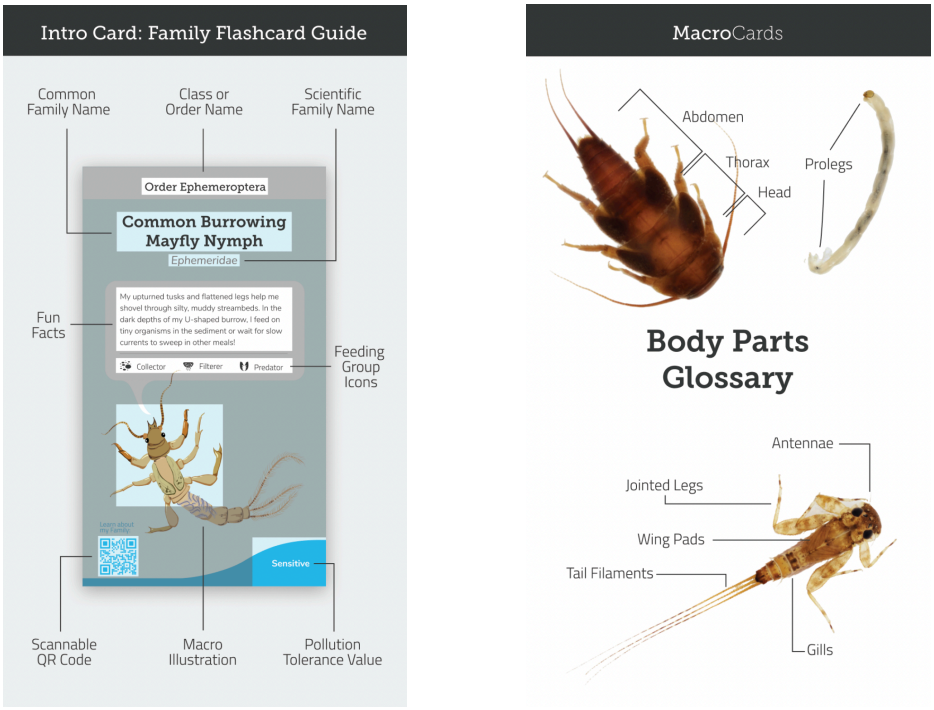
In particular, flashcard users appreciated the information about the different feeding groups, inclusion of common names and scientific names:

“I really love the way that they are organized. I really like they say how they get their food, their method...You learn lots of little tidbits...’I'm this tolerant,’ ‘I have this many legs,’...But it has a little bit more about their behaviors, so their special traits, which is fun and makes it more engaging to teach people about it.” – Novice-level

“I like the information on the back of the card. I get to know the behavior of the macro and I really like the symbols for functional feeding groups and the pollution tolerance ID.” – Intermediate-level

“I think it was helpful that they kind of lumped the organisms into feeding groups...because it helps you to make that link between, ‘This is why this particular macroinvertebrate has these features - to eat these types of things and serve this type of purpose.” – Intermediate-level

FIGURE 25: SCREENSHOT OF INTRODUCTORY FLASHCARDS



Photography by: Andrea Kautz, Carnegie Museum of Natural History
Aquatic Macroinvertebrate Card Illustrations by: Ricky Chen and Karis Wang

Interestingly, some users felt that the flashcards contained too much information to parse, whereas others thought they provided sufficient background for novices:

> *"The cards don't fit as much information on them as the app or the key, so this tool is good for beginners who are trying to get simple characteristics down for each Order. I also think it might be worthwhile to print the cards on waterproof material, just in case some folks want to use them in the field."*
> – Intermediate-level

> *"When I first looked at them, the amount of information on the cards was a bit overwhelming and I wasn't sure what I should be focusing on."*
> – Intermediate-level

Flashcard users also appreciated the formatting on the cards, and the presence of both photographs and drawings of the various aquatic macroinvertebrates:

> *"The flashcards are helpful because they have both a real photo of the organism and a drawn image. The drawn images make it easier to see some of the key identifying characteristics on the organism."* – Intermediate-level

> *"I liked how they were color coded... so if you're not familiar with them, that's really cool and a good way to keep them organized. I also liked how they had the hand drawn image as well as a photograph of the macros because sometimes it's hard to see those identifying characteristics in actual photos."*
> – Intermediate-level

Recommendations For Improvements to the Printed Flashcards

Flashcard users had a few suggestions for improving their functionality. Some shared that the listing of some organisms by Class and others by Order had been confusing. Additional information that users thought would be helpful on the cards included photographs demonstrating the actual size and scale of the insects, differing views of the macroinvertebrates, and specific feature labels:

> *"Some of the photographs make it difficult to see certain characteristics of the organism. For example, I think it would be helpful to have a large photo of both the top and bottom of the organism, so you can count the number of legs and things easier on the front of the card."* – Intermediate-level

> *"It would have been helpful to have all of the body parts labeled on the Order Flashcards. It would have provided examples of how the different parts may appear on different macros. For example, labeling the mouth parts on the 'Alderflies & Dobsonflies' Flashcard and the wing pads on the 'Stoneflies' Flashcards. For the Family Flashcards, it would have been helpful to have the major identifying, not just the distinguishing or unique, parts labeled on the pictures to provide a 'real life' example."* – Expert-level

“The Damselflies card shows ‘five sharp stiff points,’ but doesn’t include three gills.” – Intermediate-level

CONCLUSION

The PocketMacro app, printed key, and flashcards effectively supported users in practicing aquatic macroinvertebrate identification. In turn, practicing with any of these tools positively impacted participants’ understanding, accuracy, confidence, and ability to observe key diagnostic features at the Order and Family levels. However, the print and digital tools had slightly different affordances, which contributed to how users perceived their effectiveness. For example, app users highlighted the ability to zoom in closely to see specific features as one of their favorite aspects of the PocketMacro app, and, the app was subsequently perceived as significantly more useful than the flashcards or printed key for seeing Order level characteristics during practice and in the future. In contrast, users appreciated the ability to compare Orders via the full collection view printed on the back of the dichotomous key, but they thought the resource was significantly less useful than the flashcards or app for supporting accurate identification or learning about aquatic macroinvertebrates. Similarly, while the flashcards were viewed as a powerful tool for studying Orders, the app and printed key were thought to be better for conducting actual identifications of unknown specimens. Yet the flashcards and app were considered to be more effective for seeing Family level features. Thus, each of the three tools has different strengths that suggest that using a combination of the three resources to practice and improve one’s identification skills may yield the most positive results.

APPENDIX A: SURVEY INSTRUMENTS

Thank you for your interest/participating in our study! The purpose of this survey is to find out a little bit about your background to see if you qualify to participate in the larger study.

Part 1 of the pre-survey will ask some demographic information about your prior experiences with and knowledge about macroinvertebrates. It should take about 10 minutes to complete./ Part 1 of the post-survey will ask you about your experiences using the tools provided in this study. It should take about 20 minutes to complete.

Part 2 is a practice quiz where you will try to identify 21 macroinvertebrates to Order (Family if you can). Just take your best guess, and you can skip any you're unsure about. You'll have up to 90 minutes to complete this section. You will need to complete the quiz in one sitting. If you are not ready now, you can close this window and come back at a later time.

Pre-Only: **When you complete the pre-survey, you will be entered into a drawing for one of thirty $20 online gift cards. If you are selected to participate in the larger study, you will be contacted by a member of the research team.** You'll be asked to watch a short six-minute video on macroinvertebrate identification and you'll be sent tools by mail or email. You'll practice doing ID for at least 90-minutes with that tool, and then be asked to take another survey.

You'll receive a **$30 online gift card**, some print ID resources, as well as a voucher to take the Society for Freshwater Science Certification Program Exam ($20 value). If you are one of the ten individuals who is selected to participate in a follow-up phone interview, you will receive an additional $20 online gift card.

Please contact *[redacted contact information],* if you have any questions about this study.

Rockman et al Cooperative, Inc. (REA) is the independent research group that is leading the evaluation. REA team members may use your responses in reports, publications, or presentations, but we won't share any of your personal information. If you choose to share your contact information, we will only contact you in regards to the gift card, to send you study materials and additional information about study participation. Completing the survey is voluntary, but we will not send a gift card to those who do not provide their email address at the end of the survey. There are minimal anticipated risks for participating. You can opt out of the study at any time by emailing *[redacted contact information].*

This survey is being conducted as part of: **Learning to See, Seeing to Learn: A sociotechnical system supporting taxonomic identification activities in volunteer-**

based water quality biomonitoring. This research is funded by the National Science Foundation (NSF AISL Award #1623969).

This project has been reviewed and approved by the Heartland Institutional Review Board. Questions concerning your rights as a participant in this research may be addressed to the Executive Director at Heartland IRB. [redacted contact information].

After reviewing the information above, please click on one of the options below. If you wish to participate, please click the "I AGREE" button and you will be taken to the survey. If you do not wish to participate in this study, please select "I DO NOT AGREE" or close this browser window.

____I AGREE to participate in this study. Please take me to the survey.
____ I DO NOT AGREE to participate in this study.

Please type your signature here to confirm your willingness to participate: _____

PRE-SURVEY ONLY

1a.) Have you ever received training in how to do aquatic macroinvertebrate identification?

___Yes ___No

1b.) If yes: Please describe the training you had - when, where, and with what organization:

2a.) Have you ever visited the website macroinvertebrates.org before?

___Yes ___No

2b.) Have you ever participated in a training or webinar where macroinvertebrates.org resources were introduced or demoed?

___Yes ___No ___I don't know

3.) Which best describes you? Check all that apply.

____ I am a classroom teacher
____ I am an informal educator (i.e., I work at a museum, library, afterschool program, or summer camp)
____ I am a student.
____ I am a trainer who leads workshops on how to identify benthic macroinvertebrates.
____ I am a science professional who works with benthic macroinvertebrates in my job.

____ I am a science professional who does not work directly with benthic macroinvertebrates in my job.
____ I work with benthic macroinvertebrates in some other capacity (e.g., volunteer water monitoring).
____ Other (Please Specify): _____

4a.) Which of the following best describes you? Check all that apply.
____ I have collected macroinvertebrate biomonitoring data **in the past**.
____ I am **currently** involved in an organization where I collect macroinvertebrate biomonitoring data.
____ I am **planning** to become involved in collecting macroinvertebrate biomonitoring data in the future, but do not currently do so.
____ I have **never** collected macroinvertebrate biomonitoring data, and do not plan to do so in the future.

____ I have engaged students or volunteers in lessons or programming about aquatic macroinvertebrates **in the past**.
____ I **currently** engage students or volunteers in lessons or programming about aquatic macroinvertebrates.
____ I am **planning** to engage students or volunteers in lessons or programming about aquatic macroinvertebrates, but do not currently do so.
____ I have **never** engaged students or volunteers in lessons or programming about aquatic macroinvertebrates, and do not plan to do so in the future.

4b.) If you plan to or already collect macroinvertebrate biomonitoring data, please name any organizations you volunteer for/or to whom or what entities you contribute your data:

5.) Your Gender
____ Male
____ Female
____ Non-binary
____ Prefer to Self-Describe:_____
____ Prefer not to say

6.) Your Age (in years): _____

7.) Race (Check all that apply)
____ White/Caucasian
____ African American Hispanic or Latinx
____ Asian
____ Native American or Pacific Islander
____ Middle Eastern
____ Other (Please Specify): _____

If you are selected to be part of this study, we will be mailing materials to you. **Please provide your mailing address below.** *Note: We will only use your address to send ID tools to you by mail.*
Mailing Address:
City/State:
Zip Code:

BOTH PRE & POST SURVEY QUESTIONS – PART 1

1a.) Your Name (First & Last): _____

1b.) Your Email Address: _____

2.) On a scale from 1 to 10, with 1 being, *"I have no familiarity at all with aquatic macroinvertebrates"* and 10 being, *"I am an aquatic macroinvertebrate expert,"* how knowledgeable would you say that you were/are about aquatic macroinvertebrate identification…

	1	2	3	4	5	6	7	8	9	10
Knowledge or aquatic macroinvertebrates										

3.) How confident are you in your ability to do the following:

	Not at all confident (1)	Somewhat confident (2)	Confident (3)	Very confident (4)	Not applicable (5)
Collect aquatic macroinvertebrates samples					
Determine water quality based on aquatic macroinvertebrate identification					
Use paper tools to identify aquatic macroinvertebrates					
Use digital tools to identify aquatic macroinvertebrates					
Teach others how to identify aquatic macroinvertebrates					

Engage students or volunteers in learning about macroinvertebrates and freshwater environments					
Access tools and resources I need to improve my knowledge of aquatic macroinvertebrates					
Access tools and resources I need to improve my teaching of this subject					

BOTH PRE & POST SURVEY QUESTIONS – PART 2
Macroinvertebrates Identification Practice Quiz

In the quiz that follows, you will be asked to identify 21 aquatic macroinvertebrates to Order and to Family if you can. **You can use your own prior knowledge or any print or digital resources you already have.** Please answer the questions to the best of your ability. If you don't know the right answer, just use your best guess. If you do not know what a specimen is called, you can skip it and come back to it using the back button. Make sure to hit submit at the end of the quiz.

Please set a timer for 90 minutes and do your best to complete the quiz in this time. Press START on your timer when you click the forward button at the bottom of this screen. Responses that go over 90 minutes may not be accepted.

A key with the correct Order and Family Level names for all specimens will be provided to you when the study has been completed.

Critters 1-21
What Order is this critter?

___Plecoptera ___Diptera ___Megaloptera ___Ephemoptera

___Trichoptera ___I'm not comfortable making a selection

How do you know – What features make you think so? _____
[NOTE: Only displayed for 11 Orders]

How confident are you in your ID to ORDER?

___Not at all confident ___Somewhat confident ___Confident ___Very confident

Would you like to identify this organism to Family?

___Yes ___No

What Family is this critter? _____

How confident are you in your ID to Family?

___Not at all confident ___Somewhat confident ___Confident ___Very confident

Well done! The quiz is complete.
Please answer the remaining questions below.

What resources did you use during the quiz? (Check all that apply)
___My own prior knowledge
___ Field guide/book (e.g. Voshell, Aquatic Entomology, Wiggins Trichoptera)
___ Key (e.g. Maryland Family Key, Stroud Dichotomous Key, other paper-based keys)
___Macroinvertebrates.org Key
___Macroinvertebrates.org Flashcards
___PocketMacro app
___Macroinvertebrates.org website
___Other printed resources (please specify)
___Other digital resources (please specify)

POST-SURVEY ONLY

1a.) Please indicate how much you DISAGREE or AGREE with each of the following statements:

The PocketMacro App/The Printed Key/The Flashcards...	Strongly Disagree (1)	Disagree (2)	Neither Agree, Nor Disagree (3)	Agree (4)	Strongly Agree (5)	Not Applicable / I did not use the tool for this purpose
Made it easier for me to **see relevant features** for identifying aquatic macroinvertebrates						
Increased my **confidence** in identifying aquatic macroinvertebrates						

Increased my **accuracy** in correctly identifying aquatic macroinvertebrates						
Increased the **quality** of the data I feel I can report						
Helped me **see differences** between insect groups						
Provides me with an **effective way to continue practicing** how to identify aquatic macroinvertebrates outside of trainings						
Is better than other tools/materials I've come across **to help me learn** about aquatic macroinvertebrates						

1b.) What was most helpful about the PocketMacro App/Dichotomous Key/Flashcards in improving your ID skills?

2.) Please indicate how much you DISAGREE or AGREE with each of the following statements:

The PocketMacro App/ Printed Key/ Flashcards...	Strongly Disagree (1)	Disagree (2)	Neither Agree, Nor Disagree (3)	Agree (4)	Strongly Agree (5)	Not Applicable / I will not use the tool for this purpose
Will be **easy to integrate** into my current program offerings or lessons						
Will **enhance** my current program offerings or lessons						
Enables me to **better meet and address educational standards**						

Is better than other tools/materials I've come across to make aquatic macroinvertebrates **more accessible to others**						
Is better than other tools/materials I've come across **to engage students or volunteers with aquatic macroinvertebrates**						

3a.) How useful was the <u>PocketMacro app/Printed Key/Flashcards during your practice</u> for doing the following?

	Not at all Useful (1)	Somewhat Useful (2)	Useful (3)	Very Useful (4)	Not Applicable
To ID an unknown specimen					
To view images of a macroinvertebrate more closely					
To see **ORDER** level characteristics/features of a macroinvertebrate					
To see **FAMILY** level characteristics/features of a macroinvertebrate					

3b.) How useful will the <u>PocketMacro app/Printed Key/Flashcards be to you in the future</u> for doing the following?

	Not at all Useful (1)	Somewhat Useful (2)	Useful (3)	Very Useful (4)	I did not use the app for this purpose
To ID an unknown specimen					
To view images of a macroinvertebrate more closely					
To see **ORDER** level characteristics/features of a macroinvertebrate					

To see **FAMILY** level characteristics/features of a macroinvertebrate					
To quiz myself/ practice ID					
To help others learn about macroinvertebrates					

4.) Overall, how helpful were the following sections of the Pocket Macro app?

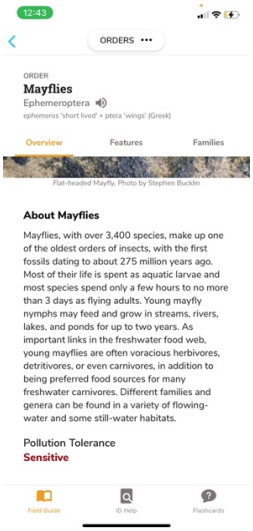
	Not at all Helpful (1)	Somewhat Helpful (2)	Helpful (3)	Very Helpful (4)	I did not use this section (N/A)
Field Guide 					
ID Help 					
Flashcards 					

5.) How useful were the following features of the Field Guide section?

Not at all useful (1), Somewhat useful (2), Useful (3), Very Useful (4), I did not use this feature (N/A)

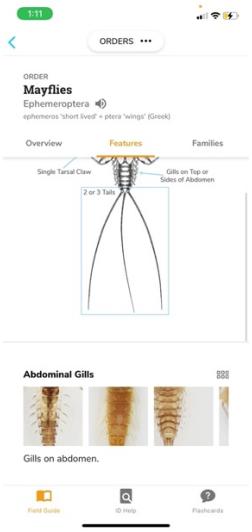
Please circle your answer below each image.

Pollution Tolerance Information



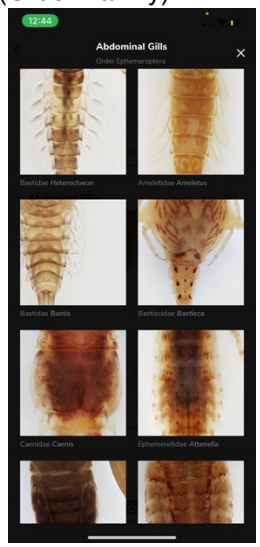
N/A 1 2 3 4

Diagnostic Features (Order/Family)



N/A 1 2 3 4

Gallery of Diagnostic Features (Order/Family)



N/A 1 2 3 4

Flip Views Functionality (Dorsal/Ventral/Lateral)

N/A 1 2 3 4

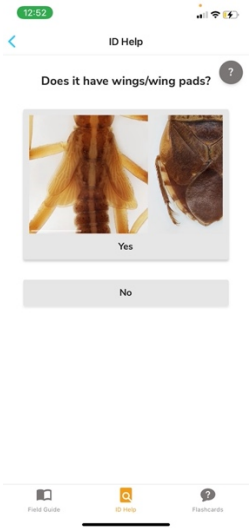
Zoomable Macroinvertebrate Photographs

N/A 1 2 3 4

6.) How useful were the following features of the ID Help section?

Not at all useful (1), Somewhat useful (2), Useful (3), Very Useful (4), I did not use this feature (N/A)
Please circle your answer below each image.

Guided Dichotomous Key Questions

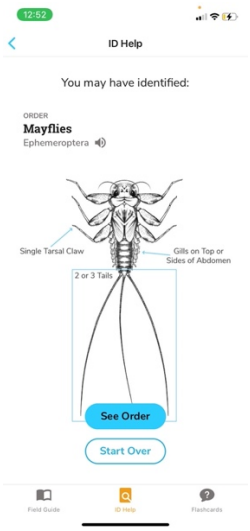


N/A 1 2 3 4

Zoomable ID Key (*if available*)

N/A 1 2 3 4

ID Key Result Page



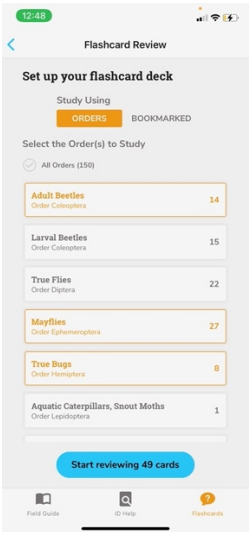
N/A 1 2 3 4

7.) How easy was it to use the following features in the Flashcard section?

Very difficult (1), Somewhat difficult (2), Somewhat easy (3), Very easy (4), I did not use this feature (N/A)

Please circle your answer below each image.

Flashcard Set-up Functionality



N/A 1 2 3 4

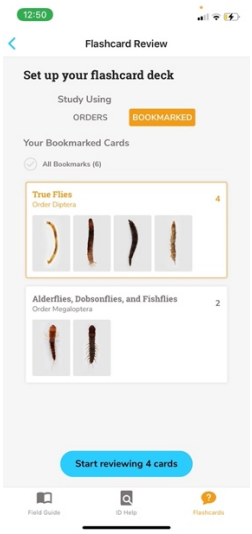
Flipping, Swiping, Zooming Functionality

N/A 1 2 3 4

8.) How likely are you to use the following features in the Flashcard section?
Not at all likely (1), Somewhat likely (2), Likely (3), Very Likely (4), I did not use this feature (N/A)

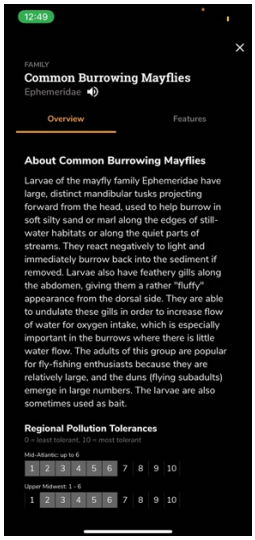
Please circle your answer below each image.

Flashcard Bookmark Feature



N/A 1 2 3 4

Family Level "See More" Feature



N/A 1 2 3 4

9.) Are you interested in participating in a 30-minute follow-up phone interview to share more about your experiences using the provided tools? If selected for an interview, you will receive an additional $20 gift card.
___ Yes ___No

10.) Would you like us to contact you via email about future study opportunities?
___ Yes ___ No

APPENDIX B: INTERVIEW INSTRUMENT

1.) So first, I'd like to know why you're interested in learning more about aquatic macroinvertebrate identification.
    a.) How do you plan to use your aquatic macroinvertebrates knowledge?

2.) What's challenging about aquatic macroinvertebrate ID?

3.) What kinds of tools or resources have you used in the past to practice aquatic macroinvertebrate ID?
    a.) What have you liked about those tools?
    b.) Where have those tools fallen short?

4.) What did you like about using [X] tool to practice IDing macros this week?
    a.) What were some of the benefits of using this tool? [Prompt: Can you describe some of the ways this tool helped you?]
    b.) Was there a time that the tool was really useful while doing an ID? [Prompt: If yes: How so? How did the tool make things easier?]

5.) Was there anything you didn't like as much about the tool?
    a.) What were some of the drawbacks of using this tool?
    b.) Was there a time that doing an ID was hard using this tool? [Prompt: If yes: How so? Where did you have trouble? / What kinds of roadblocks did you hit while using this tool?]
    c.) What else do you need (if anything) from tools like this one to make them more useful to you?

6.) What kinds of things did you learn from using this tool?

7.) Would you recommend using this tool to others? [Prompt: Why or why not?]

8.) How did the tool you used this week compare to other resources you've used or seen?

9.) How do you plan to use this tool in the future?
    a.) For yourself?
    b.) With others?

10.) When doing aquatic macroinvertebrates ID, do you prefer print resources like printed keys or flashcards or digital resources like websites or apps? [Prompt: What makes you say that?]

a.) Print & Digital condition: Did you have a preference in the tools we gave you - the key, the flashcards, or the app?

11.) Is there anything else you'd like to share about your experiences using this tool?

APPENDIX C: USAGE LOG

Welcome to the study! Please download this file to your desktop. Over the next week, write down every time you use tools to practice ID using the log below. Make sure you are doing this every time you use the PocketMacro App, key, or flashcards.

Please specify whether you were using the PocketMacro App, key, or flashcards in the "Tool Used" column. If you used any additional print or digital tools when you were practicing IDs, please list them in the "Tool Used" column as well.

Date	Time Started Using Tool	Time Stopped Using Tool	Tool Used	How did you use the tool?

What do you like about using the Pocket Macro App?

What's hard about using the Pocket Macro App?

What do you like about using Flashcards?

What's hard about using the Flashcards?

What do you like about using the key?

What's hard about using the key?